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Peripheral wetland habitats and vegetation of the Leschenault Inlet estuary

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Abstract

Along the Leschenault Inlet estuary shore, interactions between ancestral landforms comprising the eastern shores, dune dynamics and the young western barrier dune shore, hydrodynamic processes, estuarine coastal processes, estuarine sedimentation, and a variable Holocene sealevel history, have resulted in a varied peripheral shore and wetland types. The shoreline habitats include supratidal tidal flats (vegetated dominantly by samphire), high tidal platforms (vegetated dominantly by samphire or rushes), tidal embayments (residing between dune corridors), high tidal platforms and dune interfaces, in zones of freshwater seepage (vegetated dominantly by rushes), cliffed sandy shores where coastal erosion is incising into dunes, steep dune shores where dunes are encroaching into the estuary, beachridges, spits, bar-and-lagoon complexes, stranded (relict) sand platforms, the Collie style deltaic complex, and the Preston style deltaic complex. Five broad categories of vegetation fringe the Leschenault Inlet estuary, classified on structure, salinity of habitat, and location relative to shore: 1) saltmarsh; 2) estuarine fringing forest; 3) fringing vegetation; 4) sandy rise vegetation; and 5) freshwater vegetation (forest and disturbance-related assemblages). Saltmarshes, comprising samphire and rush formations, develop in saline tidal areas. Estuarine fringing forest, typically small saltwater sheoak (*Casuarina obesa*), saltwater paperbark (*Melaleuca cuticularis*), paperbark (*Melaleuca viminea*), and swamp paperbark (*Melaleuca rhaphiophylla*), occurs as elevation increases and where soilwater salinity is not extreme. Fringing vegetation consists of emergent species living more or less permanently in shallow water (*e.g. Schoenoplectus validus*). Sandy rise vegetation occurs on the crest of barrier sand bars, on margins of high coastal sand dunes, or on low estuarine beach dunes. Freshwater fringing vegetation is close to the estuary in areas receiving substantial freshwater input.

There have been some marked changes in the peripheral vegetation of the estuary since 1941, some occurring in the vegetation alone, and some induced by estuarine coastal landform dynamics. These changes are evident as: 1) clearing of fringing vegetation; 2) decline of estuarine fringing forest; 3) encroachment of *Juncus kraussii* into the estuary; 4) colonisation of river deltas; and 5) formation of tidal lagoons or pools along the high tidal platforms.

There are four determinants at the large scale influencing the type and composition of saltmarsh present along the shore. The two most important are geomorphic setting and physical estuarine coastal processes. The third is a south to north gradient in source water salinity and the fourth is anthropogenic effects. Leschenault Inlet thus presents a heterogeneous array of shore habitats, resulting from a variable upland geomorphic setting (*i.e.* the south to north gradient along the west coast, and east coast *vs* west coast *vs* north coast setting), the variable coastal processes operating on the coast (to generate progradational mud flats *vs* cliffed dune shores *vs* bar-and-lagoon complexes *vs* tidal platforms), upland to estuarine groundwater hydrodynamics and interactions, deltaic build-up at river mouths, and a complex sealevel history to develop stranded estuarine landforms. In the Leschenault Inlet the complex array of estuarine coastal habitats, and the salinity gradients developed therein have resulted in a range of vegetation units that are distributed in mosaics and gradients across the various habitat types of the shoreline. In this context, Leschenault Inlet estuary represents a classic classroom for student studies and research into estuarine peripheral vegetation ecology. From this perspective, the shoreline habitats and vegetation comprising the periphery of the Leschenault Inlet estuary rank as most significant along the south-western coast of the Swan Coastal Plain, and ranks with the Walpole-Nornalup Inlet system which itself is located in the richest botanical district in south-western Australia.

Keywords: peripheral vegetation, saltmarsh, Leshenault Inlet, estuary, south-western Australia.

Introduction

For a small, relatively simple and young (wholly Holocene) estuary, Leschenault Inlet has generated a range of environmentally distinct habitats. This paper describes the development of geomorphic units (shore types) and habitat types fringing the estuary, and the various peripheral vegetation formations therein. As such, the objectives are to: 1) provide a geohistorical framework *i.e.* the sedimentologic and geomorphic evolution of the periphery of the estuary, in order to understand the development and distribution of the peripheral geomorphic units throughout Leschenault Inlet that provide vegetation habitats; 2) describe the relationship of habitat to vegetation complexes; 3) provide an inventory of the vegetation, and

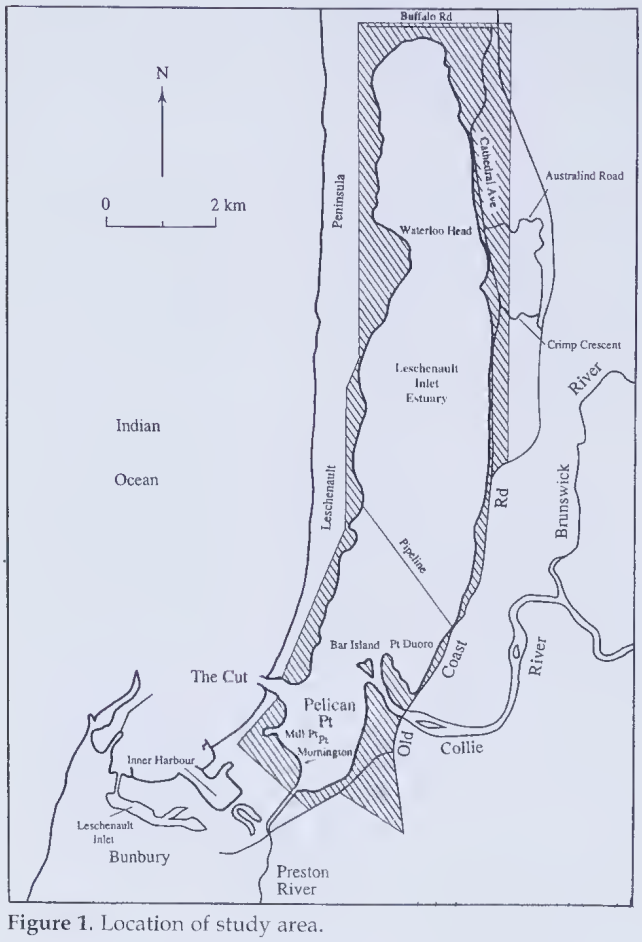


Figure 1. Location of study area.

a baseline of the vegetation associations fringing the estuary in terms of structure, composition and distribution; and 4) document the natural and anthropogenically induced changes to the peripheral vegetation of the area over the past 50 years.

Methods and terminology

Colour aerial photographs at 1:10 000 scale from the Department of Land Administration (WA) were obtained for the study area in 1989 from which sketch maps showing distribution of vegetation and vegetation type, standing water and land use (*e.g.* pasture or urban) were produced using a Zeiss Aerosketchmaster to a 1:5 000 scale. The maps were ground-truthed in the field on the 24th May, and the 8th and 21st June 1991, and annotated with relevant information on plant assemblage composition and structure and weed infestation. Plant assemblages were identified and described on the bases of structure and dominant species, after Trudgeon (1984), to provide a continuity of the description of the vegetation in this region. Unknown plant species were submitted to the WA Herbarium for identification.

Changes in the estuarine shoreline and the evolution of small scale geomorphic features, and habitats, and changes in vegetation were noted by comparing the field observations and mapping in 1991 with those evident on aerial photographs from 1941, 1966, 1975, 1977, 1982, 1986 and 1989. Examples of such changes were assessed by reducing maps of the distribution of the plant assemblages at particular places and times to the same scale using the Zeiss Aerosketchmaster.

Transects through selected habitats and vegetation units were established to describe the habitat types and vegetation. These transects were surveyed with respect to Australian Height Datum, and sites along the transect were established to describe sediments, stratigraphy, and groundwater. Data from these transects in terms of profiles, stratigraphy, and groundwater are presented in Semeniuk (2000) and Semeniuk *et al.* (2000). The extent of the study area, and the geographic locations mentioned in the text are shown in Fig 1.

The terms "peripheral habitats" and "peripheral vegetation" in this paper refer to the wholly high-tidal to supratidal habitats and vegetation, respectively, that fringe the periphery of the Leschenault Inlet estuarine lagoon. All habitats along the estuary periphery that originate from estuarine processes are incorporated in this term (*e.g.* high-tidal flats, spits, stranded platforms), including those stranded estuarine-derived landforms developed when sealevel was higher than at present. The term "saltmarsh" refers to grass, rush, sedge, and/or samphire vegetation formations that are regularly inundated and inhabit the saline to brackish environments fringing the estuary. The term "samphire" is used to denote chenopod low herbland formations. The term "mangrove" refers to tree and shrub vegetation formations that are regularly inundated and inhabit the saline to brackish environments fringing the estuary. For the tidal heights, MSL refers to mean sea level, AHD is the Australian Height Datum, and HAT refers to the highest astronomical tide.

Regional setting

Leschenault Inlet is a shallow estuarine lagoon located along the south-western coast of the Swan Coastal Plain (Semeniuk & Meagher 1981), and separated from the Indian Ocean and Rottnest Shelf by barrier dunes (Semeniuk & Searle 1985). The estuarine lagoon is located in a subtropical subhumid climate, or Mediterranean climate (Gentilli 1972), with an annual rainfall of *ca* 880 mm and annual evaporation of *ca* 1 980 mm. Tides are microtidal, with a prevailing range of 0.5 m and a maximum range of 0.9 m.

There are four main landform and estuarine units that constitute the Leschenault Inlet system; these are (Fig 2) : 1) an eastern hinterland: a high ridge of quartz sand and limestone (the Mandurah-Eaton Ridge), and lowlands underlain by limestone (the southern extremity of the Yalgorup Plain; Semeniuk 1995, 1997); 2) Leschenault Inlet itself: an elongate shore parallel, estuarine lagoon; 3) the western barrier dunes (Leschenault Peninsula): a quartz/carbonate sand barrier that bars Leschenault Inlet (Semeniuk & Meagher 1981); and 4) delta-lands, formed by the Collie River and Preston River that enter the estuarine lagoon to its southeast and south. Leschenault Inlet estuary, however, is not in a pristine condition. The nature of the internal geomorphology of the majority of the Leschenault Inlet estuarine lagoon, however, has remained unchanged.

In terms of its natural internal geomorphology, the Leschenault Inlet area has been subdivided into a number of estuarine and deltaic geomorphic units (modified from Wurm & Semeniuk 2000, and Semeniuk 2000): 1) central

and northern subtidal basins; 2) eastern and western subtidal platforms and ramps; 3) high-tidal platforms; 4) northern supratidal flat; 5) beachridges, spits, and bar-and-lagoon complexes; 6) the Collie River delta; and 7) the Preston River delta.

The central and northern basins and the aquatic eastern and western platforms and ramps, within the estuary, being subtidal or low intertidal, are not inhabited by peripheral estuarine vegetation, and are outside the scope of this paper. In the high intertidal zone, both east and west shores of the estuarine lagoon are composed mainly of herbaceous vegetated high tidal platforms (saltmarsh). The northern Leschenault Inlet is bordered by a broad supratidal flat; this surface is nearly horizontal, to very gently inclined towards the estuary, emergent by progradation, underlain by mud, and vegetated by samphire. Along the margin of the western shore, there are locally developed beachridges, spits, and bar-and-lagoon complexes. Spits emanate from eroding dune tips, projecting onto the tidal zone of the estuary, generally traversing an interdune corridor or embayment. Where spits have encroached fully across an interdune corridor or embayment, the embayment may be barred, forming a bar-and-lagoon system.

In the south-eastern part of Leschenault Inlet, the Collie River has built a triangular wave-dominated delta of distributary channels, beachridges and samphire-vegetated swales and lagoons. The remnant of the Preston River delta, in the southern extremity of the former more longitudinally extensive estuarine lagoon, is composed of linear tidal-current-aligned shoals and emergent islands, with intervening shallow channels. Emergent islands within the Preston River delta are vegetated by samphires, rushes, or mangrove in the tidal zone, and terrestrial vegetation in the supratidal zone.

Wurm & Semeniuk (2000) subdivide the estuary into four salinity fields, based mainly on the seasonal variability of the estuarine waters (Fig 2). These salinity fields are important to understanding the distribution of species comprising the peripheral vegetation in that the various water bodies therein provide the source water for recharge to the tidal flats. They are: 1) an upper estuary field where mean salinities approximate marine water, but show large variation (brackish water common in winter, and hypersaline water common in summer); 2) a middle estuary field where mean salinities approximate marine water, but with some variation; 3) a lower estuary field close to the marine source where salinities are mostly marine, with little variation; and 4) a deltaic field where salinities mostly are marine, but with marked freshwater periods during river flooding.

Across the tidal flats, there is a gradient of increasing groundwater salinity, from marine at the estuary to hypersaline towards the land. The upslope hypersalinity is diluted by freshwater seepage at the boundary with upland dunes. The three main hydrologic sources and mechanisms that maintain the peripheral vegetation are:

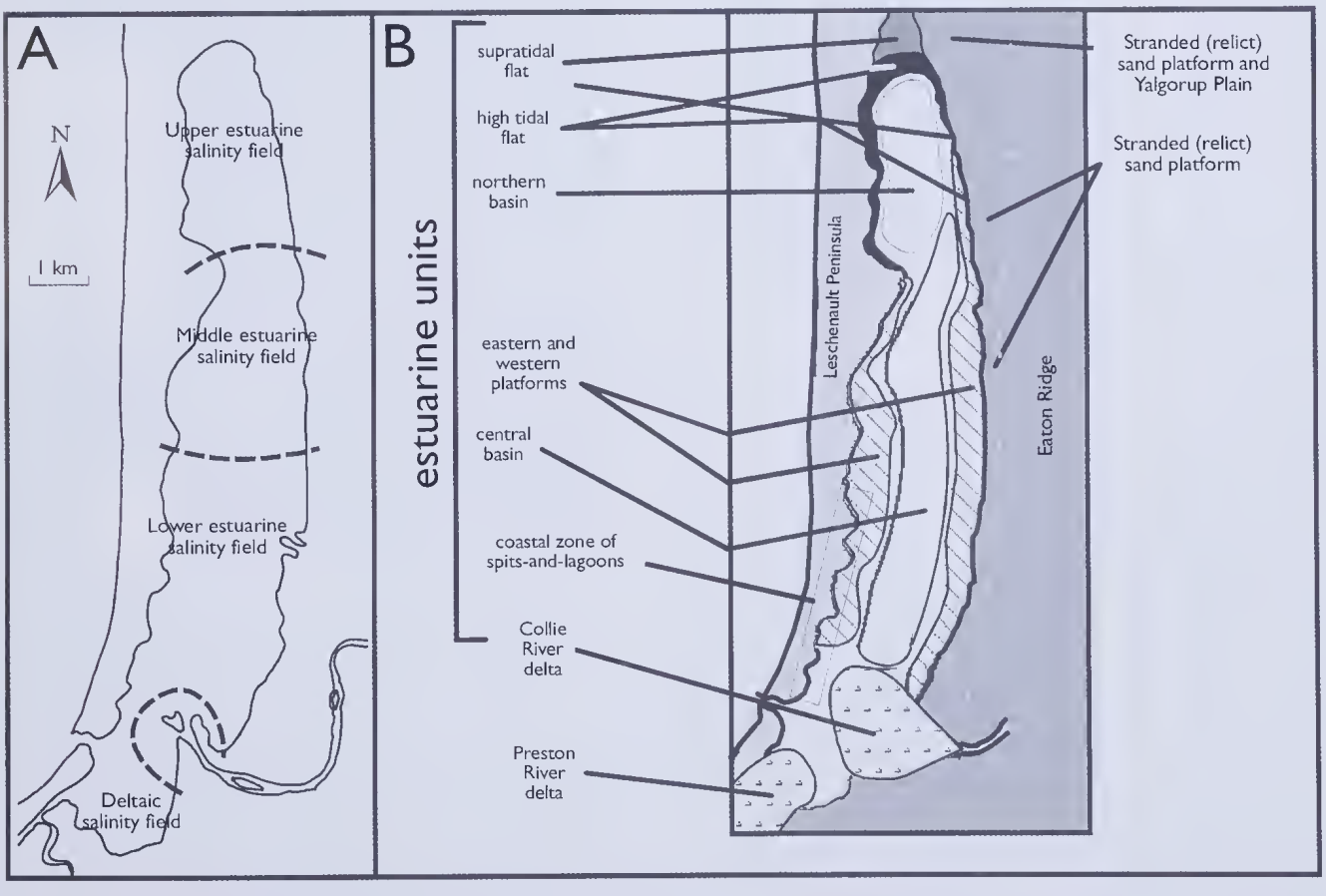


Figure 2. A: The estuarine salinity framework in Leschenault Inlet (after Wurm & Semeniuk 2000). **B:** The main landform and estuarine units comprising the Leschenault Inlet system (an eastern hinterland; Leschenault Inlet itself; the western barrier dunes; delta-lands).

1) tidal recharge that replenishes saline water to the high tidal flats; 2) meteoric recharge that directly reduces the salinity of these tidal flats; and 3) freshwater seepage from the dunes that reduces hypersalinity along the interface between the tidal flat and dune shore (Cresswell 2000).

Evolution of geomorphic units and shore types

Viewed at the largest scale, the sedimentary and geomorphic patterns of the Leschenault Inlet area are relatively simple. A shore-parallel linear barrier dune complex bars an estuarine lagoon from the open Indian Ocean. The barrier dune complex has been retreating eastwards over the estuarine sediment throughout the Holocene through a staggered series of parabolic dune incursions that spill over into the estuary (Semeniuk 1985). The sheltered interior of the estuarine lagoon is accumulating mud, muddy sand, and locally sand, and shelly equivalents of these sediments (Semeniuk 2000). To the east, these estuarine sediments onlap a hinterland of Pleistocene sediments, or onlap or interfinger with sediments derived from this Pleistocene basement.

At the smaller scale, mobile parabolic dunes directly spill into the estuary, forming sandy aprons in the aquatic environment. Laterally, muddy estuarine sediments accumulate, later to be buried by an encroaching dune. The staggered dune encroachment into the estuary, with dune sand fingers laterally alternating with muddy accumulations in sheltered corridors develop variable inter-digitating and complex interfaces between dune sand and estuarine sediment.

The main physical processes operating in Leschenault Inlet that transport, shape, and develop sediment bodies in both the estuarine environment and the peripheral geomorphic units, are: 1) wind-induced wave action on shores and platforms; 2) wind-induced currents; 3) storm waves; 4) tidal flooding; 5) tidal current erosion and transport; 6) tidal current deposition; 7) riverine flooding; and 8) wind erosion and transport. The effects of these processes in shaping the sedimentary environments are described below in terms of the process and its main location, and its main effects.

Wind-induced wave action on shores and east and west platforms reworks sand on the eastern platform, generally removing mud. It also reworks sediment on the western platform partly removing mud, and erodes the sandy shores and the small mud cliff shores. Wind-induced currents on the east and west shores transport mud reworked by wave action into suspension to the northern basin and supratidal environments and transport sand, shaping the spits and bars. Storm waves on east and west shores, the north-facing sector of Collie River delta, and the northern supratidal flat build low storm beachridges, transport shells onto the high tide and supratidal zone, winnow sediment along the shore, and erode the small cliff shores. Tidal flooding within the Preston River delta and the artificial tidal delta shapes and deposits sediment on the tidal delta and Preston River delta. Tidal current erosion and transport along the east and west shores also erodes and transports sand along the shore to build spits and bars. Tidal current deposition on the high-tidal platform and the northern mud basin and supratidal flat accumulates mud onto the high-tidal environments. Riverine flooding at the mouth of the Collie River delta injects riverine sand and mud into the estuary. Wind erosion/transport on the east- and west-located sandy beaches develops small beachridges and dunes that fringe the estuary shore, and builds the spits and bars.

The general accretionary sedimentary history of Leschenault Inlet has been complicated by a variable sealevel history, which has resulted in the stranding of some geomorphic units, or in the placing of some estuarine-derived units close to the water table (hence they have become estuarine peripheral wetlands). The history of sealevel is described by Semeniuk (1985) in three stages: 1) sealevel stage 1: 7 000-4 500 years BP, with sealevel 2-3 m below present level; 2) sealevel stage 2: 4 500-*ca* 3 500 years BP, with sealevel 3-4 m above present; and 3) sealevel stage 3: 2 800 years BP to present, with sealevel at present height.

Peripheral geomorphic units or wetlands developed during sealevel stage 1 have not been preserved. The effect of the sealevel stage 2 highstand is evident on the eastern shore: the eastern platform extant during the 3-4 m sealevel highstand is preserved now as an elevated platform underlain by structureless quartz sand, whose surface is 1-2 m above present sealevel (this surface would have been 1-1.5 m *below* sealevel during the highstand). However, most of the peripheral geomorphic units, habitats, and wetlands are related to present sealevel (sealevel stage 3).

With sealevel at its present position, sedimentation mainly involves: 1) development of the eastern platform as a wave-built structure at a level related to the current sealevel; 2) development of the western platform/ramp as parabolic dunes encroach into the estuary; 3) development of spits, evolving to bars and associated lagoons along the crenulate western shoreline; 4) development of high-tidal platforms through tidal mud accretion; 5) winnowing of mud from subaquatic platforms and the central basin, and its transport northwards into the northern basin; 6) shoaling of the northern basin to develop the northern supratidal flat; 7) injection of fluvial sand and mud into the estuary to develop deltas; and 8) tidal reworking of the Preston River delta to develop tidal-dominated estuarine landforms.

Shoreline habitats

The following shore types, and their vegetation, either developed earlier in the Holocene (Stage 2 sealevel history), or formed with sealevel at its present position (Stage 3 sealevel history), are recognised along the periphery of the Leschenault Inlet estuary: 1) supratidal tidal flats (vegetated dominantly by samphire); 2) high tidal platforms (vegetated dominantly by samphire or rushes); 3) tidal embayments (residing between dune corridors); 4) high tidal platforms and dune interfaces, in zones of freshwater seepage (vegetated dominantly by rushes); 5) cliffed sandy shores where coastal erosion is incising into dunes; 6) steep dune shores where dunes are encroaching into the estuary; 7) beachridges; 8) spits; 9) bar-and-lagoon complexes; 10) stranded (relict) sand platforms; 11) the Collie style deltaic complex; and 12) the Preston style deltaic complex. A brief description of these units is given below and a selection of the larger units are shown in Fig 3.

The supratidal tidal flats are broad and extensive, low

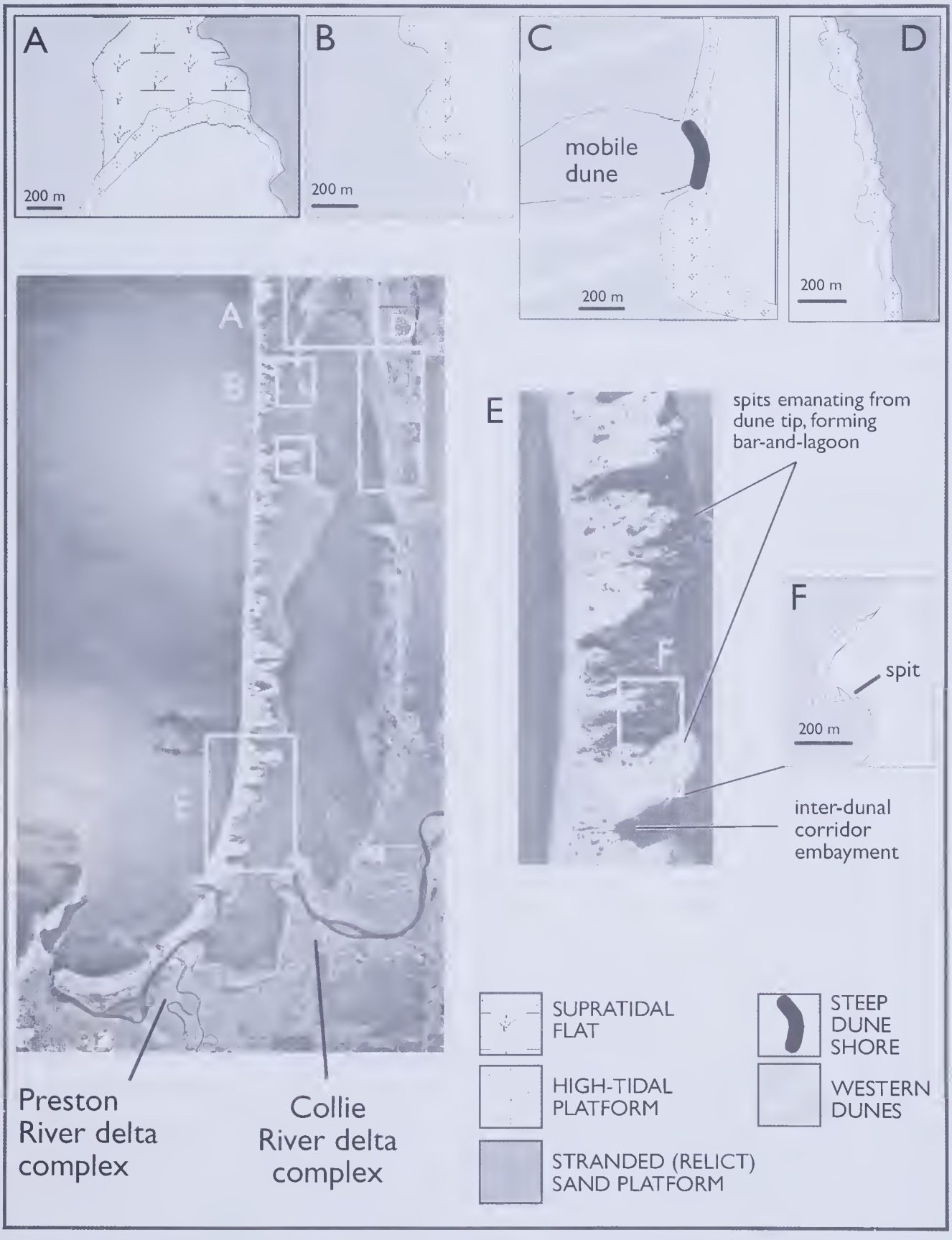


Figure 3. Typical location and detail of the various habitat units: supratidal tidal flats (vegetated dominantly by samphire); high tidal platforms (vegetated dominantly by samphire or rushes); tidal embayments (residing between dune corridors); high tidal platforms and dune interfaces, in zones of freshwater seepage (vegetated dominantly by rushes); cliffed sandy shores where coastal erosion is incising into dunes; steep dune shores where dunes are encroaching into the estuary; beachridges; spits; bar-and-lagoon complexes; stranded (relict) sand platforms; the Collie style deltaic complex; the Preston style deltaic complex.

gradient flats, at and above HAT, underlain by mud, and vegetated by samphires, situated along the northern margin of the estuary. The high tidal platforms are broad and lengthy, low-gradient flats between MSL and HAT, vegetated by samphire or rushes, locally containing shore-parallel low relief mud bars, and intervening shallow shore-parallel lagoons, particularly in western and north-western locations, and commonly terminated at their estuary end by a small cliff (< 30 cm high). They are underlain by mud, located along the north-eastern margin and entire western margin of the Inlet. Narrow platforms also border the eastern margin of the estuary. The tidal embayments (residing between dune corridors) are broad, but areally restricted, low-gradient tidal flats grading to barred water bodies, at MSL to above HAT, underlain by mud, and located along south-western margins of the estuary. The high tidal platforms and dune interfaces are narrow, low gradient flats, situated at and above HAT, underlain by muddy sand and sand, and vegetated by rushes. They are located along the south-western and mid-western margins of the estuary. Cliffed sandy shores are narrow cliff zones located along south-western and mid-western margins of the estuary, and are formed where coastal erosion is incising old dunes. Steep dune shores are narrow, moderate gradient flats, situated at and above HAT, underlain by sand. They are located along the south-western and mid-western margins of the Inlet where dunes are encroaching into the estuary. Beachridges, low-relief, shore-parallel bars of sand formed at and above HAT, are located along western and eastern margins of the estuary. Spits are low relief shore-parallel bars of sand emanating from an eroding dune tip, traversing an embayment, formed at and above HAT. They are located along the western and eastern margins of the estuary. The bar-and-lagoon complexes are broad, but areally restricted, low gradient tidal flats and barred water bodies, at MSL to above HAT, underlain by mud, and barred by a sand body, and located along the south-western margin of the estuary. Stranded (relict) sand platforms are broad, low-gradient flats, underlain by sand with locally developed relict beachridges and sand waves. Their surfaces are situated up to 1 m above HAT. They are located along the eastern margin of the estuary. The Collie River deltaic complex overall is a triangular low-relief fluvially-dominated to wave-dominated deltaic landform projecting into the estuary at its south-eastern margin, composed of distributary channels, abandoned channels, levee banks, beachridges, swales, subaerial deltaic flats, subaqueous deltaic mouth bars and shoals, and delta front sand flats, shoals and sand waves. It is a fluvial dominated delta with a component of wave reworking developing the beachridge complexes on the northern sector. The Preston River deltaic complex overall is a triangular low-relief tide-dominated deltaic landform originally located along the southern part of the estuary, and comprised of distributary channels, oval to elliptical (emergent to submerged) shoals oriented parallel to the tidal flow, abandoned channels, and levee banks.

Overview of peripheral vegetation

The peripheral vegetation of the Leschenault Inlet estuary has been noted, mapped, or described as part of scientific studies, floral surveys, and unpublished reports by a number of authors, including Diels (1906), Sauer (1965), Smith (1985), Saenger *et al.* (1977), Schwinghammer (1982), Semeniuk *et al* (1978), Semeniuk & Meagher (1981), Trudgeon (1984), Bridgewater (1982, 1985, 1989), Pen (1992), Cresswell & Bridgewater (1998), and Bridgewater & Cresswell (1999). Also, Semeniuk *et al.* (1989) describes Quindalup vegetation pertinent to Leschenault Inlet. Biogeographically, the peripheral vegetation of the Leschenault Inlet estuarine lagoon belongs to Mediterranean Saltmarsh Biogeographic Zone of Bridgewater (1982), and the junction of the Mediterranean and Western transition zones of Bridgewater & Cresswell (1999). This indicates the key boundary position of the Leschenault Inlet in biogeographical terms, a point recognised for the hinterland region by Bridgewater (1994).

Cresswell & Bridgewater (1998) recognise a range of vegetation associations from south-western Australia, of which the following are found peripheral to the Leschenault Inlet estuary: 1) Avicennio-Sarcocornietum quinqueflorae P B Bridgewater 1982, with the identifying species *Avicennia marina* and *Sarcocornia quinqueflora;* 2)Sarcocornio-Suaedetum australis P B Bridgewater 1982, with the identifying species *Sarcocornia quinqueflora* and *Suaeda australis.* In the Leschenault area the sub-association, *halosarcietosum halocnemoidis* (with the diagnostic species *H. halocnemoides halocnemoides*); 3) Juncetum kraussii P B Bridgewater 1982, with the identifying species *Juncus kraussii* and *Samolus repens;* and 4) Halosarcietum halocnemoidis P B Bridgewater 1982, with the identifying species *Halosarcia halocnemoides* ssp *halocnemoides.*

Halosarcietum pergranulatae P B Bridgewater 1982, with the identifying species *Halosarcia pergranulata* ssp *pergranulata* is another association that has been noted in this region, and potentially could have occurred in the Leschenault Inlet area. However, Trudgeon (1984) did not record the identifying species, and Pen (1992) also did not find this association within his surveys. The association may be restricted to the Peel-Harvey estuary.

Peripheral shore types, habitats, and vegetation

Vegetation fringing Leschenault Inlet estuary can be divided into five types based on structure, salinity of habitat, and location relative to the shore : these are discussed below in terms of vegetation type, large-scale estuarine and salinity setting, smaller scale vegetation types. The saltmarsh is located on supratidal tidal flats, high tidal platforms, tidal embayments (residing between dune corridors), high tidal platforms and dune interfaces, and Collie River deltaic complex, saline to brackish high-tidal platforms, and swales and abandoned channels of the deltas. The saltmarsh formations consist of samphire flats and heath, and open to closed low sedgelands, rushlands, and herblands. The estuarine fringing forest is located on supratidal tidal flats, high tidal platforms, tidal embayments (residing between dune corridors), stranded (relict) sand platforms, the Preston River deltaic complex, and saline to freshwater tidal to supratidal settings. It consists of mangrove, or saltwater paperbark, or some freshwater paperbark. Fringing vegetation is located on supratidal tidal flats, and stranded (relict) sand platforms, and freshwater supratidal setting. It consists of emergent sedge, and sedge and mat grass formations. Sandy rise

vegetation occurs on cliffed sandy shores, steep dune shores, beachridges, spits, part of bar-and-lagoon complexes, on the Collie River and Preston River deltaic complexes, as well as freshwater dune margins, spits, bars, and beaches. It consists of open shrubland, woodland, closed sedgeland, low closed Acacia scrub and thicket. Freshwater vegetation (forests) occurs on stranded (relict) sand platforms, and the mostly freshwater setting of the eastern shore stranded platform. It consists of sedgeland, and low open - closed forest. Freshwater vegetation (that is disturbance-related) is located on stranded (relict) sand platforms, and the mostly freshwater setting of the eastern shore stranded platform. It consists of remnant forest and woodlands with weed or pasture dominant in understorey, and weed assemblages.

Saltmarshes, comprising samphire and rush formations, develop in saline tidal areas. Estuarine fringing forest, typically of the small saltwater sheoak (*Casuarina obesa*), saltwater paperbark (*Melaleuca cuticularis*), paperbark (*Melaleuca viminea*), and swamp paperbark (*Melaleuca rhaphiophylla*), occurs as the elevation increases and where soilwater salinity is not extreme. Fringing vegetation consists of those emergent species which live more or less permanently in shallow water (*e.g. Schoenoplectus validus*). Sandy rise vegetation occurs on the crest of barrier sand bars, on margins of high coastal sand dunes, or on low estuarine beach dunes. Freshwater fringing vegetation occurs close to the estuary in areas receiving substantial freshwater input, either from surface inputs (*i.e.* drains, creeks) or from groundwater seepage which typically occurs at the base of a ridge or sand dune.

In areas subject to frequent disturbance, plant assemblages may develop which are marked by an absence of native plant regeneration and/or exhibit a high degree of weed infestation and heterogeneity. For example, relic native trees forming parkland over pasture are largely prevented from regenerating because of continuous disturbance such as grazing and fires, and the population becomes increasingly aged. Disturbance-related plant assemblages also develop where environmental conditions have not reached an equilibrium with changing land use over a period of many years. In such cases some native plant species undergo decline, others become established, while others maintain their populations, and at the same time ephemeral weeds establish opportunistically. Such assemblages appear chaotic and contrast greatly with the homogeneity of relatively stable native plant assemblages.

The vegetation types within the various shore types and peripheral habitats are briefly described in Table 1 below. The main species composition of the vegetation types are described later in the text.

From a large scale perspective, the peripheral vegetation occurs in eleven main geographic areas : 1) northern supratidal flats; 2) western high-tidal platforms; 3) south-western high-tidal platforms; 4) south-western shore of spits and bar-and-lagoons; 5) north-eastern high-tidal platforms; 6) eastern high-tidal platforms; 7) eastern stranded platform; 8) barrier/tidal platform edge; 9) steep dune shores; 10) Collie River delta; and 11) Preston River delta. The distribution of the vegetation types around the estuary is presented as a series of maps. Fig 4 shows the location

Table 1. Relation between habitat type and vegetation

Habitat unit	Vegetation types
supratidal tidal flats	vegetated dominantly by saltmarsh (samphire)
high tidal platforms	vegetated dominantly by saltmarsh (samphire, followed to landward by rushes)
tidal embayments	vegetated by saltmarsh (samphires and rushes)
high tidal platforms and dune interfaces, in zones of freshwater seepage	vegetated dominantly by saltmarsh (samphires and rushes), backed by fringing forest
cliffed sandy shores	no peripheral estuarine vegetation
steep dune shores	mangroves, or rushes
beachridges	sandy rise vegetation (see text)
spits	sandy rise vegetation (see text)
bar-and-lagoon complexes	sandy rise vegetation (see text), and freshwater vegetation
stranded (relict) sand platforms	*Juncus kraussii* rush, followed to landward by low forests of *Melaleuca cuticularis* and occasionally *Casuarina obesa*, or by *Melaleuca rhaphiophylla* low forests
Collie River deltaic complex	mixed assemblages as mosaics according to intra-delta habitats: samphire in the sediment-filled abandoned channels, rushes lining the channels, and dune vegetation on spits and sand ridges
Preston River deltaic complex	mixed assemblages as mosaics according to intra-delta habitats: samphires and scattered mangrove colonising shoal crests, rush along channel margins and the interface between the barrier-dune and delta, mangroves bordering the emergent delta shoals, dune vegetation or Casuarina bordering emergent delta shoals

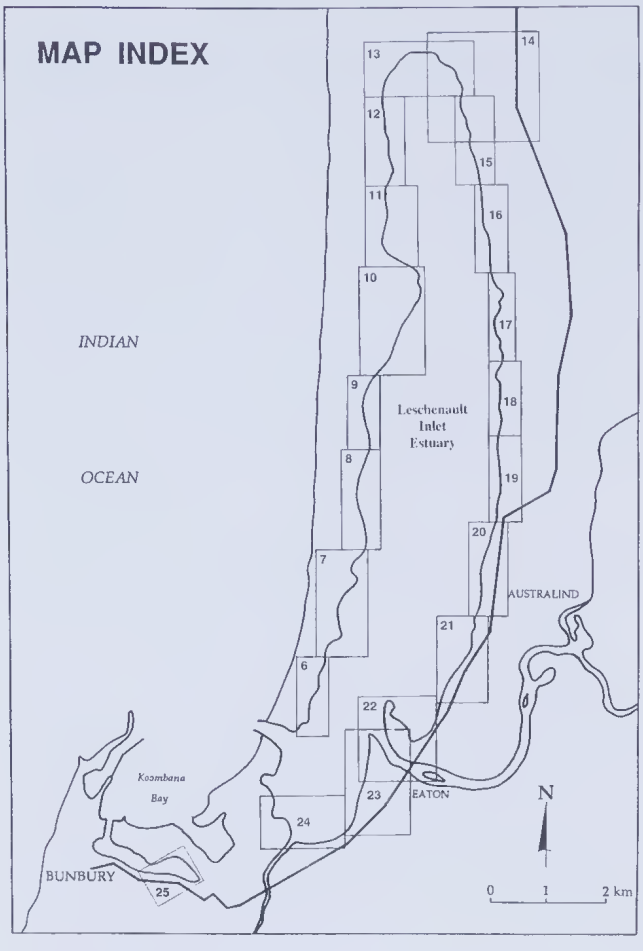


Figure 4. Location of detailed maps.

of detailed maps. Fig 5 shows the key to the vegetation units of the maps. Figs 6-25 show details of vegetation mapping along the estuarine shore. These maps provide a baseline of the distribution of vegetation types along the shore of the estuary in 1989.

Saltmarsh vegetation

***Juncus kraussii* closed rushland**. Much of the southern half of the estuary is ringed at the water's edge with a dense band of sea rush *J. kraussii*, 0.5 - 1.0 m high, up to 1.5 m high. The halophytes, *Sarcocornia quinqueflora* and *Suaeda australis*, are often found amongst it and sometimes the small saltwater sheoak *Casuarina obesa*, saltwater paperbark *Melaleuca cuticularis* and the shrub sea heath *Frankenia pauciflora* are found scattered across it. *Juncus kraussii* closed rushland also fringes the saltmarshes on their landward side, particularly along the western foreshore. On the landward side, bands of *J. kraussii* are often fringed with knotted club-rush *Isolepis nodosa* or twig-rush *Baumea juncea* and the herb marsh saltbush *Atriplex prostrata*. Along the water's edge along the lower southern foreshore, fringing bands of water couch *Paspalum vaginatum* are common. Along the eastern foreshore, particularly along its middle region, the *J. kraussii* closed rushland is being invaded by the alien grasses *Cynodon dactylon* (couch) and *Pennisetum clandestinum* (kikuyu) and *Carpobrotus edulis* (pigface).

***Sarcocornia quinqueflora* saltmarsh complex** (*e.g.* Figs 6, 9-19). This saltmarsh complex contains five assemblages which often are impractical to separate for mapping exercises in the field as they merge over broad areas. The characteristic common to all four assemblages is the pres-

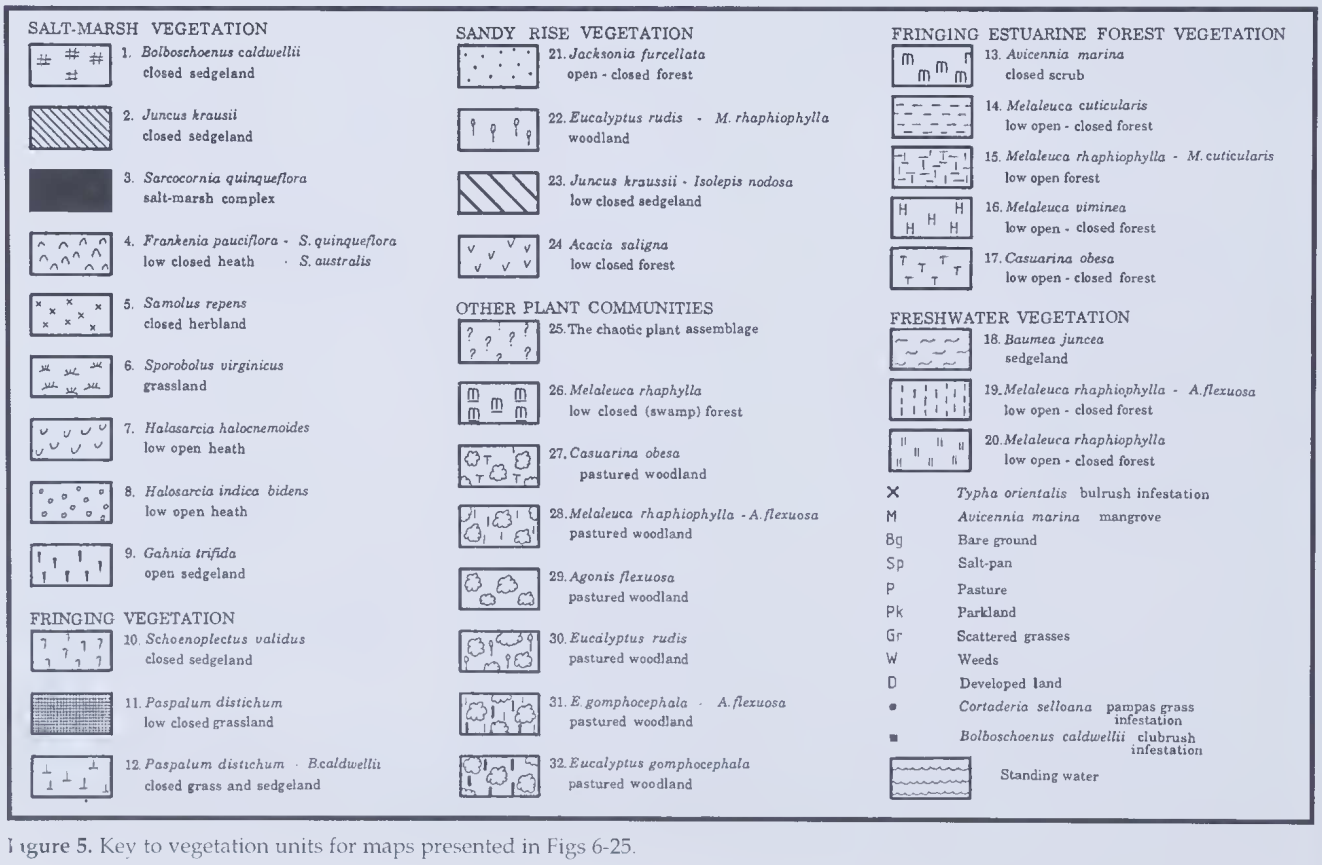
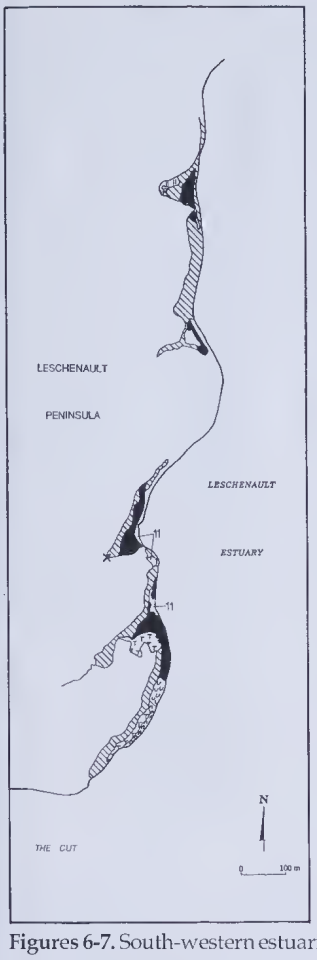
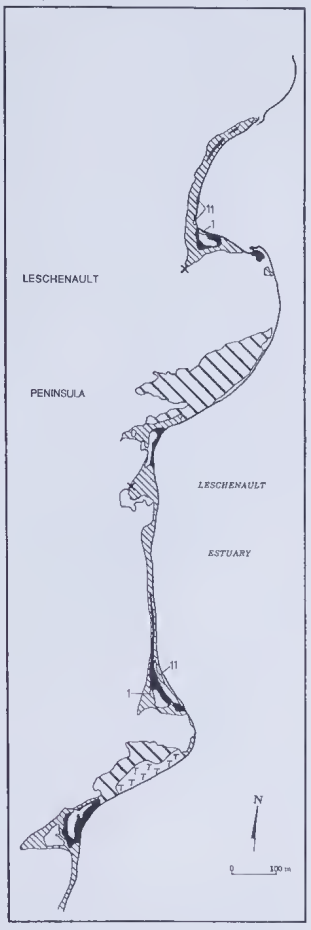
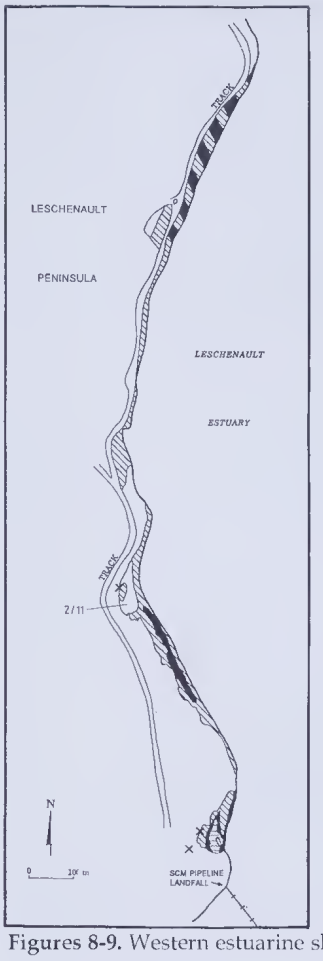


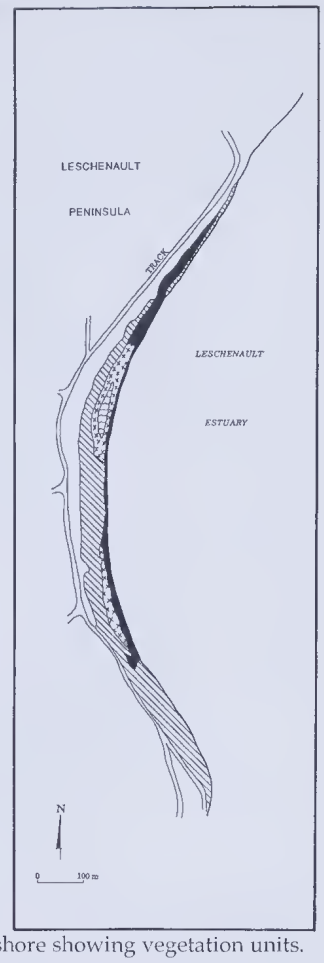
Figure 5. Key to vegetation units for maps presented in Figs 6-25.



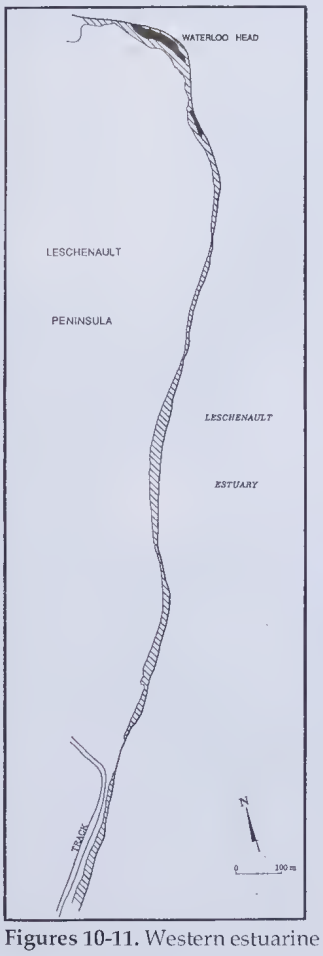


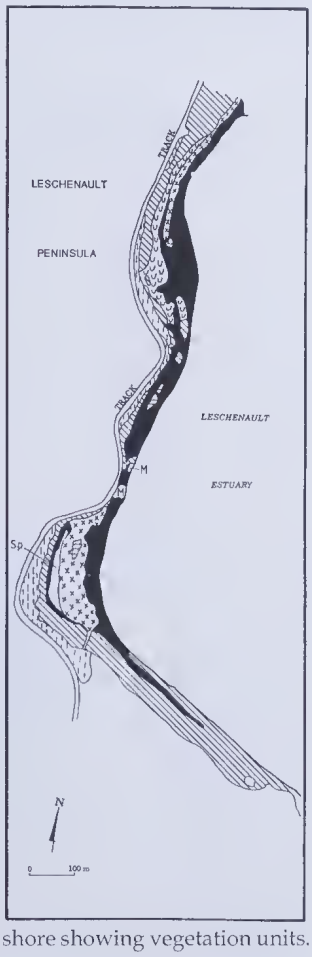
Figures 6-7. South-western estuarine shore showing vegetation units



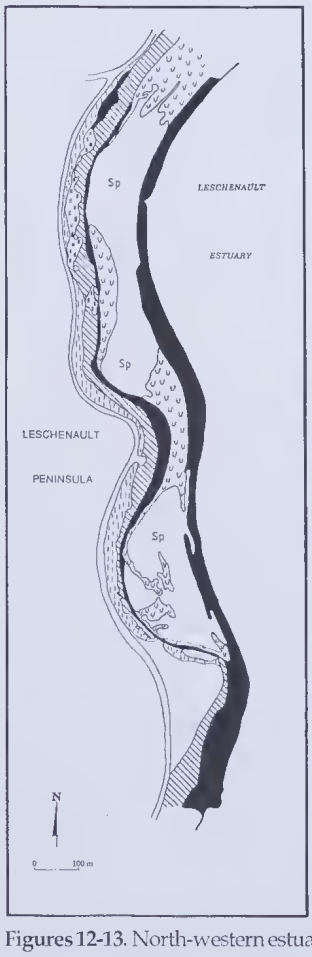


Figures 8-9. Western estuarine shore showing vegetation units.

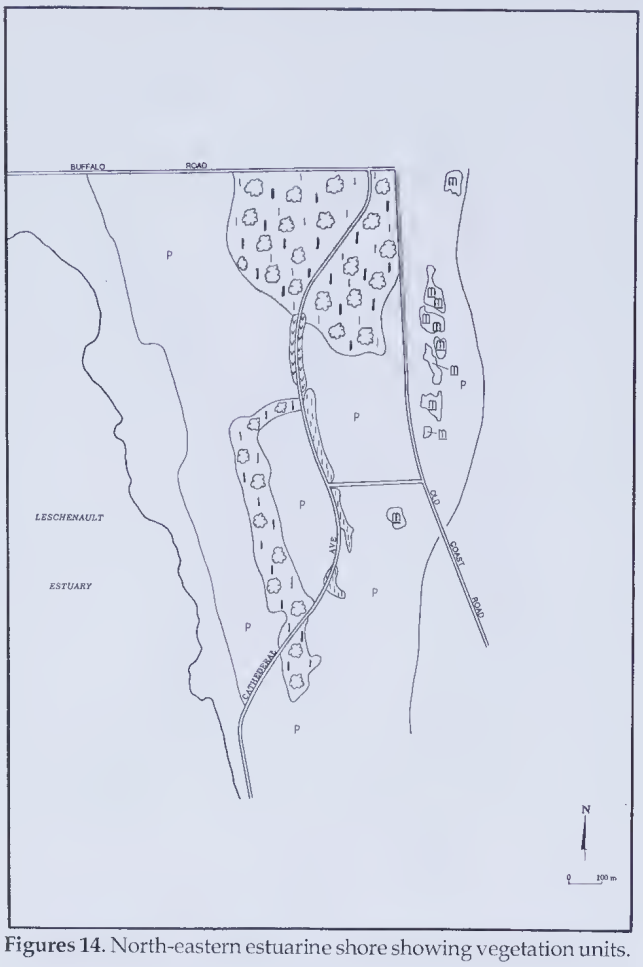




Figures 10-11. Western estuarine shore showing vegetation units.



Figures 12-13. North-western estuarine shore showing vegetation units.



Figures 14. North-eastern estuarine shore showing vegetation units.

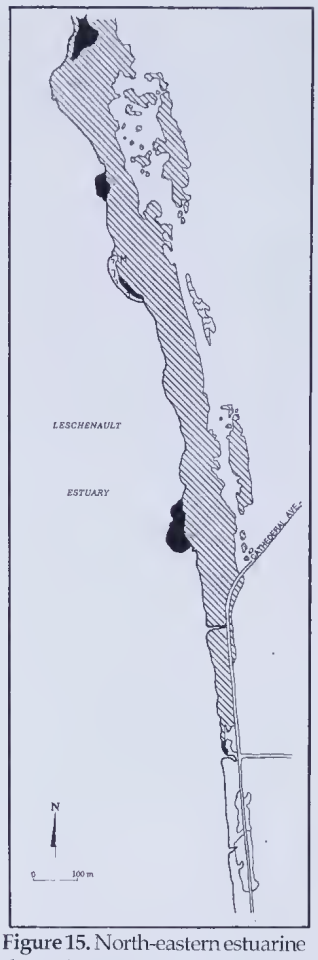


Figure 15. North-eastern estuarine shore showing vegetation units.

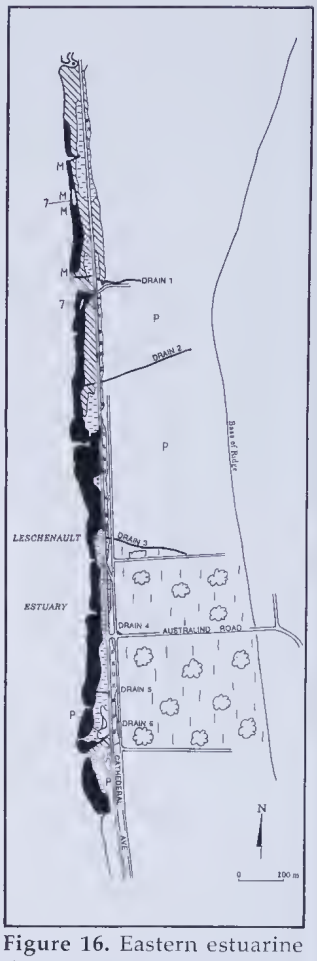
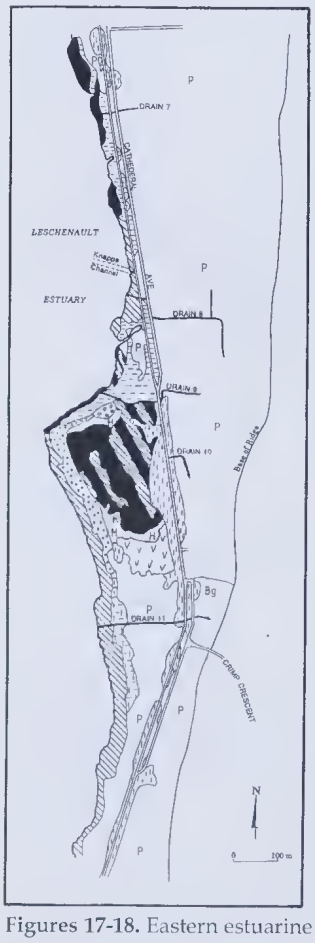
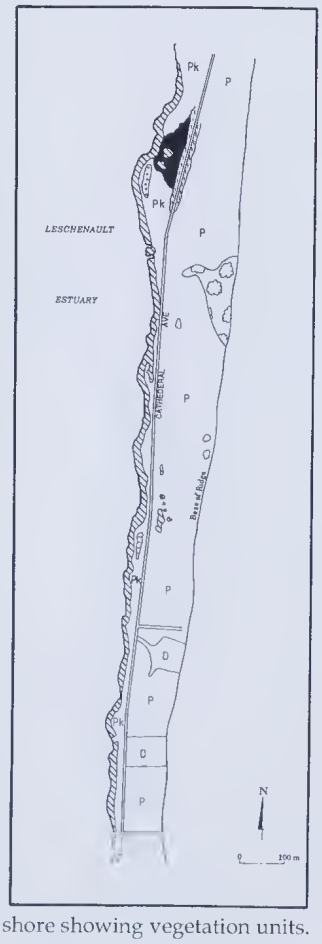
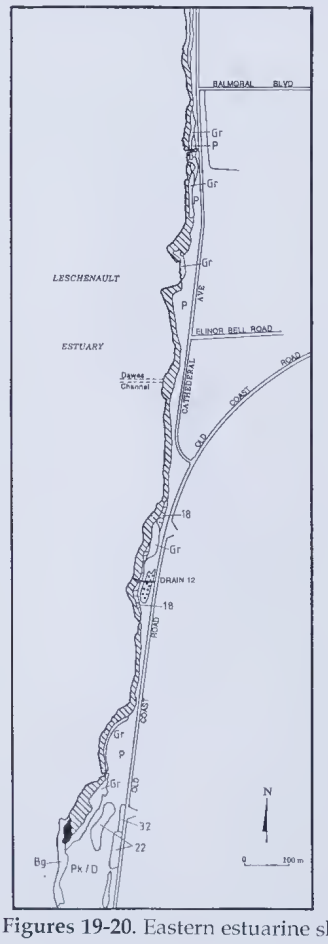


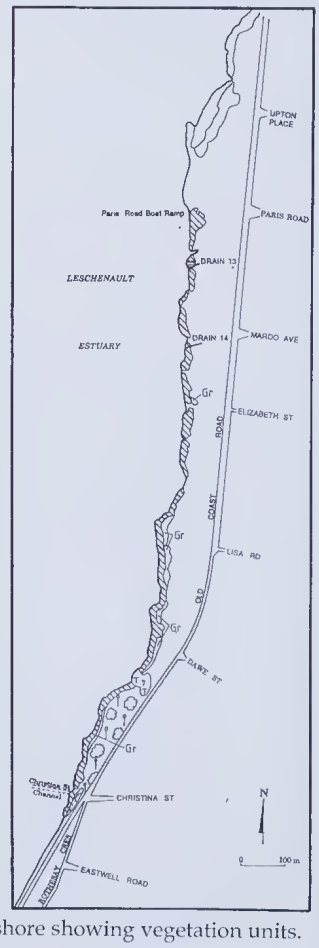
Figure 16. Eastern estuarine shore showing vegetation units.





Figures 17-18. Eastern estuarine shore showing vegetation units.





Figures 19-20. Eastern estuarine shore showing vegetation units.

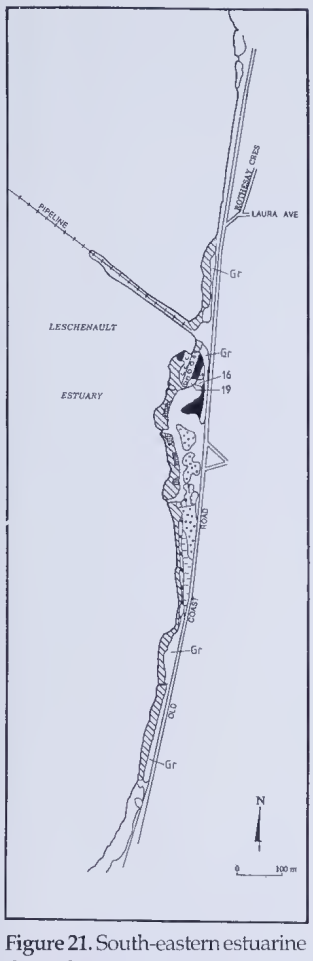


Figure 21. South-eastern estuarine shore showing vegetation units.

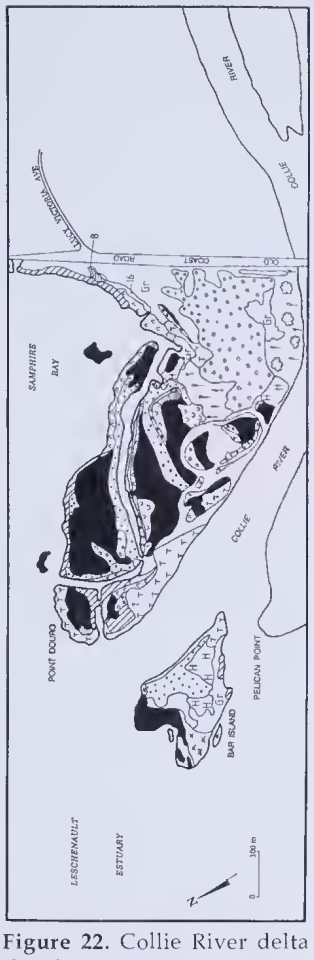


Figure 22. Collie River delta showing vegetation units.

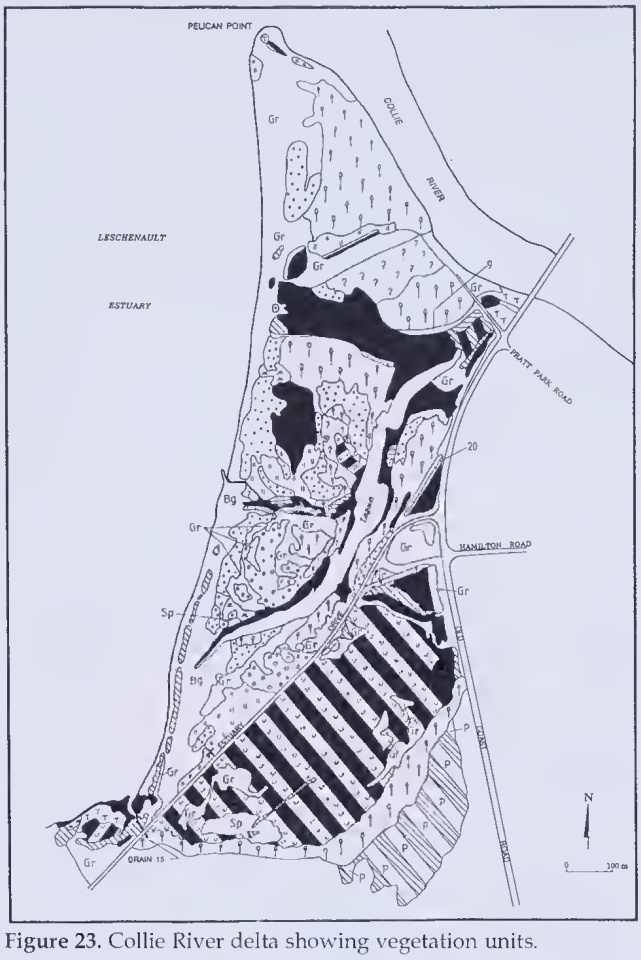


Figure 23. Collie River delta showing vegetation units.

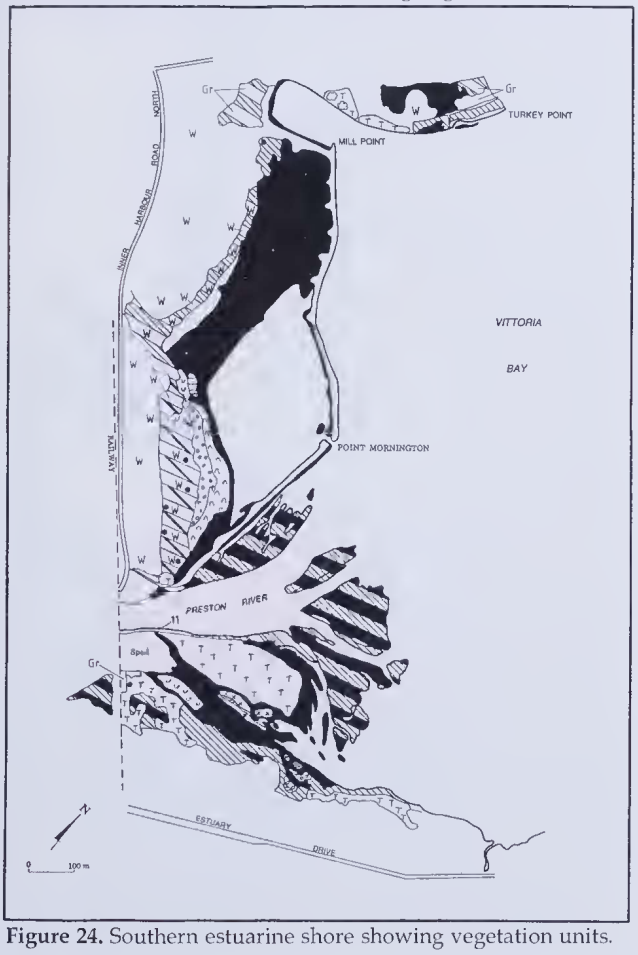


Figure 24. Southern estuarine shore showing vegetation units.

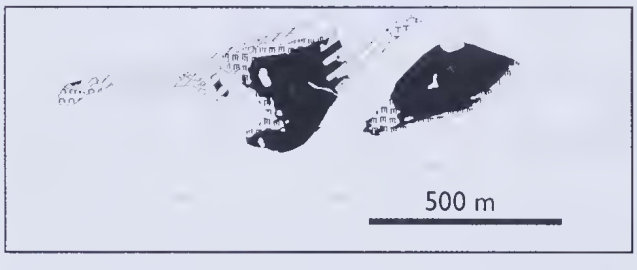


Figure 25. Detailed map of the Preston River delta showing vegetation units.

ence of the low decumbent samphire herb *S. quinqueflora*. These assemblages are:

Sarcocornia quinqueflora closed herbland: This is widely distributed around the estuary and basically forms extensive mats of samphire *S. quinqueflora*, either fringing the shoreline or behind a shoreline strip of sea rush *J. kraussii* closed rushland. The species seablite *Suaeda australis*, sea heath *Frankenia pauciflora*, streaked arrowgrass *Triglochin striata*, *Samolus repens* (a perennial small herb with no common name), *Halosarcia halocnemoides*, annual beardgrass *Polypogon monspelliensis*, saltwater couch *Sporobolus virginicus*, and sea rush *J. kraussii* can be common to sparse.

Suaeda australis - *S. quinqueflora* closed herbland: This assemblage is similar to the *S. quinqueflora* low closed herbland, except that seablite *Suaeda australis* is dominant.

Samolus repens-*S. quinqueflora* closed herbland: The small herb *S. repens* dominates this assemblage; it is found fringing with the *S. repens* closed herbland.

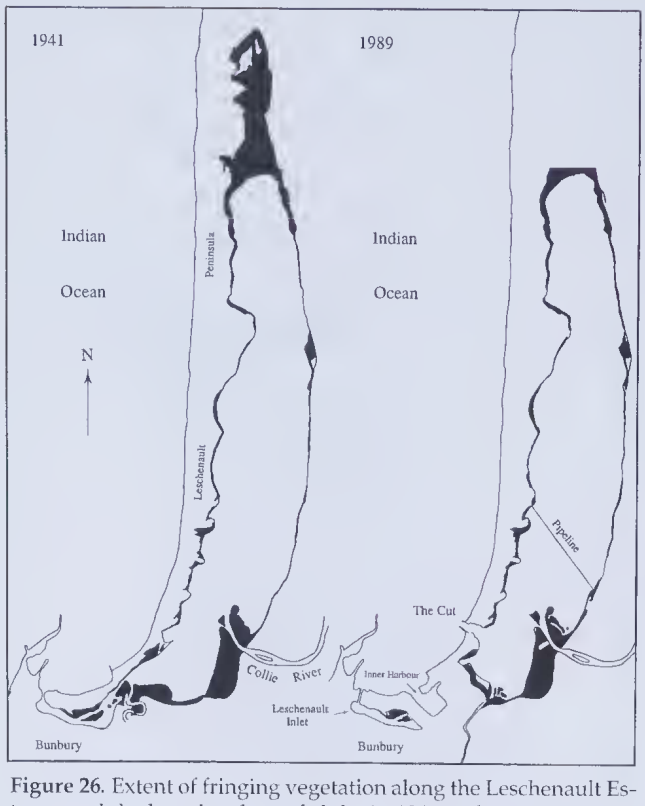


Figure 26. Extent of fringing vegetation along the Leschenault Estuary and the later Leschenault Inlet in 1941 and 1989.

Sarcocornia quinqueflora-Bolboschoenus caldwellii closed herbland: In a few localities the seasonal sedge club-rush *B. caldwellii* grows through the mats of samphire *S. quinqueflora* over the winter-spring period and then senesces.

Wilsonia humilis low open-closed herbland: *Wilsonia humilis*, a prostrate silvery decumbent herb, forms an assemblage with *S. quinqueflora* and *S. australis*, found only in the Sarcocornia complex on the remnant Preston River delta opposite the City of Bunbury.

Frankenia pauciflora-S. quinqueflora-S. australis low closed heath (*e.g.* Figs 22 and 24). Near the mouths of the Preston and Collie Rivers, seablite *Suaeda australis* and the samphire *S. quinqueflora* form a heathland of about 0.5-1 m high with the shrub sea heath *F. pauciflora*. Other species present include marsh saltbush *A. prostrata* and saltwater couch *S. virginicus*, and *Avicennia marina* and *Halosarcia halocnemoides* on the Preston River delta remnant.

Triglochin striata closed herbland. Trudgeon (1984) noted this assemblage along the Leschenault Peninsula, documenting it as a monospecific stand of the perennial herb streaked arrowgrass *Triglochin striata*. This herbland was not observed by Pen (1992). This assemblage may be considered a temporal phenomena that has no long term presence in any one site.

Samolus repens closed herbland. This consists of monospecific stands of the perennial herb *S. repens* and is found in small areas near the mouth of the Preston River (Fig 24) and in large patches along the western foreshore (Figs 9 and 11).

Sporobolus virginicus grassland. The perennial creeping grass saltwater couch *Sporobolus virginicus* sometimes forms extensive mats, occasionally with the samphire *S. quinqueflora* and saltwater couch *P. vaginatum*. Examples occur along the north-eastern corner of the estuary (Fig 12) and at Pelican Point (Fig 24).

Halosarcia halocnemoides low open heath. The shrubby samphire *Halosarcia halocnemoides* is a small shrub usually 20-30 cm in height, rarely reaching 1 m in height. It forms a low open heath in the most saline regions of the saltmarsh (Pen 1981), growing over the samphire *S. quinqueflora*, seablite *S. australis* and saltwater couch *S. virginicus*. Large stands of this assemblage are found at the northern end of the estuary (Fig 13) and formerly south of Old Coast Road near Pelican Point (Fig 23).

Halosarcia indica bidens low open heath. The shrubby *Halosarcia indica bidens* is a low shrub, usually 20-30 cm in height, reaching 2 m in height, forming an open heath in upper, saline parts of the saltmarsh (Pen 1981). On the Leschenault Inlet this assemblage also consists of the herbs seablite *S. australia* and marsh saltbush *A. prostrata*, the samphire *S. quinqueflora*, and the shrub sea heath *Frankenia pauciflora*. On Pelican Point the understorey of this assemblage also includes another samphire *Sarcocornia blackiana* and glasswort *Halosarcia syncarpa* (the latter species is found nowhere else in the study area, and the former only occasionally in other areas of the southern half of the estuary).

Gahnia trifida open sedgeland. Coastal saw sedge *Gahnia trifida* is a large tufted sedge which grows to 1.5 m, forming narrow bands on the fringe of saltmarsh between saline and relatively freshwater settings. It occurs within assemblages associated with more saline conditions and so has been classed as a marginal saltmarsh component. Stands are found at the north-eastern point of the estuary and at Pelican Point (Figs 13, 23).

Bolboshoenus caldwellii closed sedgeland. The native club-rush *Bolboshoenus caldwellii* is an ephemeral species which grows from rhizomes over the winter/spring period when salinities are low, and then subsequently senesces as salinities increase over summer and autumn. Small stands of this vegetation type are found along the Leschenault Peninsula (Trudgeon 1984), on the edge of pools or tidal lagoons. These stands were not of sufficient size for them to be consistently mapped, although occurrences of the species are marked on the maps where they have colonised stormwater-affected salt-marsh.

Fringing vegetation

Schoeneoplectus validus closed sedgeland. This tall weeping sedge which reaches 2 m, forms a small narrow monospecific stand near the north-eastern end of the estuary (Fig 15). The species often grows in shallow water and for this reason is referred to as emergent.

Paspalum vaginatum low closed grassland. The introduced creeping grass water couch *Paspalum vaginatum* occasionally forms monospecific low grassy mats on beaches (Figs 6, 7) and sometimes forms extensive mats near saltmarsh or fringing forest vegetation where the soil is waterlogged (Figs 8, 23). The species appears capable of tolerating the high salinities characteristic of the estuary.

Paspalum vaginatum-Bolboschoenus caldwellii closed grass and sedgeland. A significant stand of club-rush

Bolboschoenus caldwellii is present along the southern periphery of the Preston River mouth growing over a partially floating mat of salt water couch *Paspalum vaginatum*.

Fringing estuarine forest/scrub vegetation

Avicennia marina closed scrub or low closed forest. The white mangrove *Avicennia marina* forms stands of fringing forest in the Preston River delta area (which was once part of the narrow channel which connected the estuary to the ocean), and locally along the shore of the main Leschenault Inlet estuary. Isolated mangrove trees and shrubs are marked on the vegetation maps. The mangrove system is described in more detail in Semeniuk *et al.* (2000).

Melaleuca cuticularis low open-closed forest. The saltwater paperbark *Melaleuca cuticularis* is typically found on the saline soils bordering estuaries (Marchant *et al.* 1987), and on the Leschenault Inlet is mainly restricted to the northern part of the eastern foreshore (Figs 16 and 17). Here, it forms long and narrow bands of forest mostly to the landward of saltmarsh or fringing shoreline rushes. Only a small stand is found on the north-western corner. The understorey is mostly sea rush *J. kraussii*, *H. indica bidens*, samphire *S. quinqueflora*, seablite *S. australis*, saltwater couch *S. virginicus* and the tufted coastal saw sedge *G. trifida* are often present as are the introduced species wild aster *Aster subulatus*, marsh saltbush *A. prostrata*, couch *C. dactylon*, water couch *P. vaginatum* and dock *Rumex crispus*. The other small trees of the estuary, the swamp paperbark *M. rhaphiophylla* and saltwater sheoak *Casuarina obesa*, locally comprise part of the upper storey, as does the wattle coojong *Acacia saligna*.

Melaleuca rhaphiophylla-M. cuticularis low open forest. In one locality on the eastern foreshore, the swamp paperbark *Melaleuca rhaphiophylla* shares the upper storey with saltwater paperbark *M. cuticularis* forming a low open forest between sea rush *J. kraussii* and landward pasture. Understorey species are essentially the same as for the *M. cuticularis* low open-closed forest.

Melaleuca viminea low open to closed scrub. In saline sandy areas adjacent to saltmarsh or close to the foreshore, the small paperbark *Melaleuca viminea* forms an assemblage with a number of saltmarsh species occupying the understorey. They include *H. indica bidens*, samphire *S. quinqueflora*, seablite *S. australis*, sea rush *J. kraussii*, saltwater couch *Sporobolus virginicus*, coastal saw sedge *Gahnia trifida*, and sometimes sea heath *F. pauciflora*. *Melaleuca viminea* low open to closed scrub is found on the Collie River delta and locally along the eastern foreshore (Figs 17, 22 and 23).

Casuarina obesa low open - closed forest. The small saltwater sheoak *Casuarina obesa* forms a low open - closed forest over seablite *S. australis*, samphire *S. quinqueflora* and sea rush *J. kraussii* mostly in areas of the southern quarter of the estuary, especially along the river deltas and near "The Cut". Other species in the understorey include coastal saw sedge *G. trifida*, water couch *P. vaginatum* and sea heath *F. pauciflora*. *Casuarina obesa* also occurs with *M. viminea*, *S. virginicus*, *H. indica bidens*, *A. hypoleuca*, *W. humilis*, and *Hemichroa pentandra* on the remnant of the Preston River delta. This forest is often found along the shoreline (Figs 6, 7, 22-24).

Freshwater vegetation

***Baumea juncea* sedgeland.** To the landward of the *J. kraussii* closed sedgeland, which fringes the shoreline along most of the south-eastern shoreline, twig-rush *B. juncea* can be found fringing between the rush stand and the parkland grasses. Only seldom does it form a band of sufficient depth to enable its recognition as a separate vegetation unit. Unlike knotted club-rush *Isolepis nodosa* which is associated with sandy rises, twig-rush *B. juncea* is found in low lying areas associated with intermittent freshwater seepage. Such areas were probably favoured for clearing and pasture development in past years, and as a consequence little of the *B. juncea* closed sedgeland remains today.

***Melaleuca rhaphiophylla-Agonis flexuosa* low open-closed forest.** This assemblage, dominated by swamp paperbark and peppermint respectively, is found along the eastern shore (astride Cathedral Avenue in the vicinity of Crimp Crescent), either between high dry pasture or sandy rise vegetation and water logged pasture or between saltmarsh and the latter (Figs 16-18). The hydrologic setting suggests that this vegetation type is strongly associated with freshwater flushing from the landward side. Native understorey species such as coojong *A. saligna*, mat grass *Hemarthria uncinata*, jointed twig-rush *B. articulata*, common sword sedge *Lepidosperma longitudinale*, another tall sedge *L. gladiatum*, giant rush *Juncus pallidus* and twig-rush *B. juncea* which are typical of freshwater conditions, support this conclusion, but fringing estuarine species, including sea rush *J. kraussii*, knob sedge *Carex inversa* and coastal saw sedge *G. trifida* are also present. Numerous freshwater weeds may be present, including bridal creeper *Asparagus asparagoides*, soursob *Oxalis pes-caprae*, bracken fern *Pteridium aquilinum*, kikuyu *Pennisetum clandestinum*, an *Irridaceae* sp, arum lily *Zantedeschia aethiopica* and buffalo grass *Stenotaphrum secundatum*. This vegetation type is also found between saltmarsh, mainly *J. kraussii* closed sedgeland, and sand dune vegetation, chiefly *Agonis flexuosa* woodland to low open - closed forest, along the north-western foreshore (Figs 11 and 12). Here, members of the dune vegetation such as the shrubs *Spyridium globulosum*, *Acacia cochlearis* and cutleaf Hibbertia *Hibbertia cuneiformis*, are occasionally present, and weeds are far less common than on the eastern foreshore. Along the Leschenault Peninsula *M. rhaphiophylla-A. flexuosa* low open-closed forest is probably supported by freshwater seepage from the base of the sand dunes.

***Melaleuca rhaphiophylla* low open-closed forest.** In the Leschenault Inlet area, *Melaleuca rhaphiophylla* low open-closed forest occurs with an understorey of sea rush *J. kraussii* landward of the *J. kraussii* closed rushland. This is similar to its occurrence in some regions of the Swan River estuary where freshwater seepage is moderate. In the Leschenault Inlet area, the formation also occurs over samphire assemblages, or associated with *M. cuticularis* low open-closed forest (*e.g.* on the north-western foreshore; Figs 12 and 13). A small strip of this plant

assemblage is found along the north-western foreshore along Cathedral Avenue.

Sandy rise vegetation

***Jacksonia furcellata* open-closed scrub.** This plant assemblage, dominated by the large shrub grey stinkwood *Jacksonia furcellata*, is found on sandy rises or small sand dunes located either along the beach front, as it was formerly in the Pelican Point area (Fig 23), or behind a band of fringing rushes of sea rush *J. kraussii* along the southern-eastern foreshore (Fig 21). Common understorey species included pigface *Carpobrotus edulis* and couch *Cynodon dactylon*. Less common species are the herb *Trachyandra divaricata*, harsh Hakea *Hakea prostrata*, coojong *A. saligna*, golden spray *Viminaria juncea*, saltwater couch *Sporobolus virginicus*, swamp paperbark *M. rhaphiophylla* and saltwater sheoak *C. obesa*.

***Eucalyptus rudis-Melaleuca rhaphiophylla* woodland.** The flooded gum *Eucalyptus rudis* locally forms a woodland with swamp paperbark *M. rhaphiophylla* (*e.g.* in the highest parts of Point Douro and Pelican Point and in some areas north and south of the estuary; Figs 22 and 23). The understorey of this vegetation type has been depleted of native species, probably as a result of frequent fire and weed invasion. Mostly it consists of perennial veldt grass *Ehrharta calycina* and the herb *Trachyandra divaricata* along with a plethora of other weeds. Only some native species including grey stinkwood *Jacksonia furcellata*, common sword sedge *Lepidosperma longitudinale*, sea rush *J. kraussii* and knotted club-rush *I. nodosa*, remain today. In some adjacent areas the understorey has been completely replaced by lawn or parkland development and only the relic flooded gum *E. rudis* trees remain.

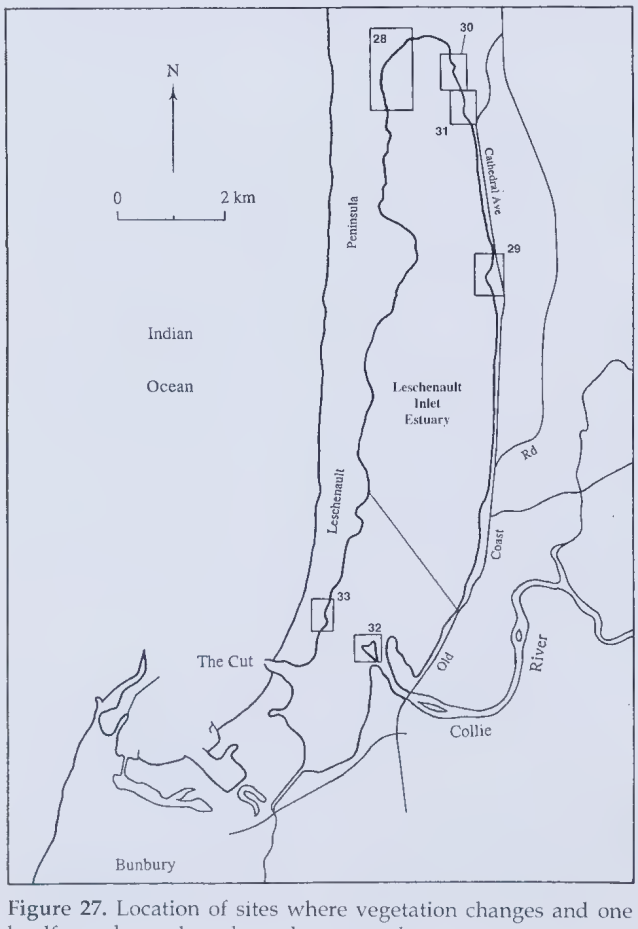


Figure 27. Location of sites where vegetation changes and one landform change have been documented.

***Acacia saligna* low closed forest.** Along the north-eastern foreshore the small tree coojong *Acacia saligna* is very common. Here it has invaded the native plant assemblages, pasture and road verges, probably as a result of frequent fires which favour many *Acacia* species. In places these occurrences are so dense that the species forms a low closed forest (*e.g.* just north of Crimp Crescent on the eastern foreshore; Fig 17).

***Juncus kraussii-Isolepis nodosa* low closed sedgeland.** Where the foreshore abuts a sand dune, as is often the case along the south-western side of the estuary, or a sandy rise, which is more commonly the case along the eastern foreshore, the knotted club-rush *Isolepis nodosa* often occurs to landward of the *J. kraussii* closed rushland. Along the western foreshore, this formation often merges with sand dune species such as red-eyed wattle *Acacia cyclops*, the large shrub *A. cochlearis*, coast daisy bush *Olearia axillaris* and cutleaf hibbertia *Hibbertia cuneiformis*. Along the eastern foreshore much of the native vegetation on the landward side of the sea rush *J. kraussii* has been cleared and replaced with parkland and consequently *J kraussii-I. nodosa* low closed sedgeland is present only as a remnant narrow strip bordering lawn.

Freshwater vegetation (forest and disturbance-related assemblages)

The chaotic plant assemblage. Over large areas of Pelican Point up until the mid 1990s the vegetation was too heterogeneous to enable the recognition of definite plant assemblages (Fig 23). A wide area of native and introduced species typical of saline and freshwater environments and a large range of weeds were present. The more successful species include swamp paperbark *M. rhaphiophylla*, paperbark *M. viminea*, sea rush *J. kraussii*, samphire *S. quinqueflora*, seablite *S. australis*, coastal saw sedge *G. trifida*, flooded gum *E. rudis*, marsh saltbush *A. prostrata*, rye grass species *Lolium* spp., water couch *P. vaginatum* and couch *C. dactylon*. It would appear that these areas were in a state of flux, probably brought about by a combination of factors including frequent fires, physical disturbance (as indicated by the irregularity of the ground surface) and frequent alteration to the salinity/freshwater flushing regime caused by the Cut, drains, nearby reclamation, and the construction of Taylor Road. Note that this area has now been developed.

***Melaleuca rhaphiophylla* low closed (swamp) forest.** Swamp paperbark *Melaleuca rhaphiophylla* forms patchy stands of closed forest over small lakes in north-eastern region of the study area (Fig 14).

Pastured woodlands. In some areas of the eastern and southern foreshores relic trees from past stands of forest and woodland assemblages remain over parkland or pasture grasses. A small stand of saltwater sheoak *C. obesa* trees over parkland can be found near Mill Point where it abuts a stand of *C. obesa* low open forest (Fig 24). A large area of

M. rhaphiophylla-A. flexuosa pastured woodland is found on the central eastern foreshore from Australind Road to the base of the ridge line (Fig 16). This suggests that the *M. rhaphiophylla-A. flexuosa* low open-closed forest was once far more extensive along the Leschenault Inlet than it is today. Peppermint (*Agonis flexuosa*) woodland is also found in the area but only in small patches (Fig 21). Flooded gum *Eucalyptus rudis* pastured woodland, probably representing the relic trees of the *E. rudis-M. rhaphiophylla* woodland, is found on Point Douro and to the north of the pipeline (Figs 20 and 22). In the most north-eastern corner of the study area *Eucalyptus gomphocephala* (tuart)-*A. flexuosa* and *E. gomphocephala* pastured woodlands are found over relatively broad pastured areas.

Vegetation changes since 1941

There have been some marked changes in the peripheral vegetation of the Leschenault Inlet estuary evident in the aerial photographs taken since 1941 (Figs 27-33). Fig 27 shows location of more detailed maps. Figs 28-33 show detailed maps of vegetation changes. Some of the changes have occurred in the vegetation alone, without changes in the habitats, and some have been induced by changes in estuarine coastal landforms. These are described in the following sections: 1. clearing of fringing vegetation; 2. decline of estuarine fringing forest; 3. encroachment of *J. kraussii* into the estuary; 4. colonisation of river deltas; 5) formation of tidal lagoons or pools along the high tidal platforms; and 6) weed invasions.

Clearing of fringing vegetation

The extent of fringing vegetation, in 1941, comprised some 700 ha of which about 350 ha remained in 1989 (Fig 26). Since this time, most of the remnant fringing forest and newly formed saltmarsh on Pelican Point has been destroyed by development. Large areas of samphire which colonised dredging spoil and artificial lagoons along the southern end of the estuary also have been destroyed by harbour development.

Further substantial losses of fringing vegetation have occurred to the north of Buffalo Road through clearing and drainage for agriculture, with loss of glasswort *H. halocnemoides* low closed heath and fringing forests of most probably saltwater paperbark (*M. cuticularis*), swamp paperbark (*M. rhaphiophylla*) and peppermint (*A. flexuosa*), and to the south where large areas, including most of the original estuary mouth, have been reclaimed for harbour construction. Much of the narrow strip of fringing vegetation along the eastern foreshore also has been cleared on the landward side corresponding to the elevated stranded platform, leaving an even narrower strip today. However, along the western shore of the Leschenault Inlet estuary foreshore, the narrow band of fringing vegetation remains largely intact.

Relic trees present over pastured floodplain to the east of Cathedral Avenue and south of Buffalo Road, and corresponding to the elevated platform, indicate that these areas once supported swamp paperbark *M. rhaphiophylla* low closed forest, *M. rhaphiophylla- A. flexuosa* low closed forest, and forests and woodlands dominated by tuart *E.*

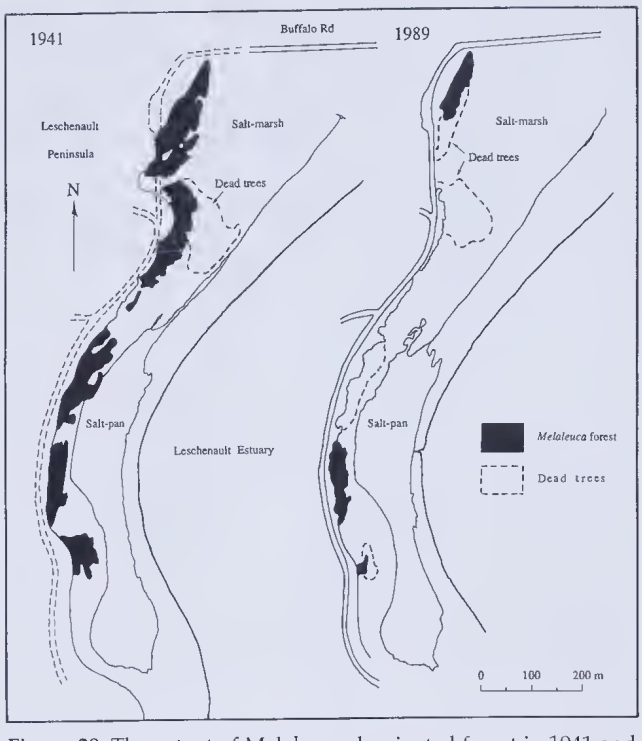


Figure 28. The extent of Melaleuca dominated forest in 1941 and 1989 in the north-western corner of the Leschenault Inlet.

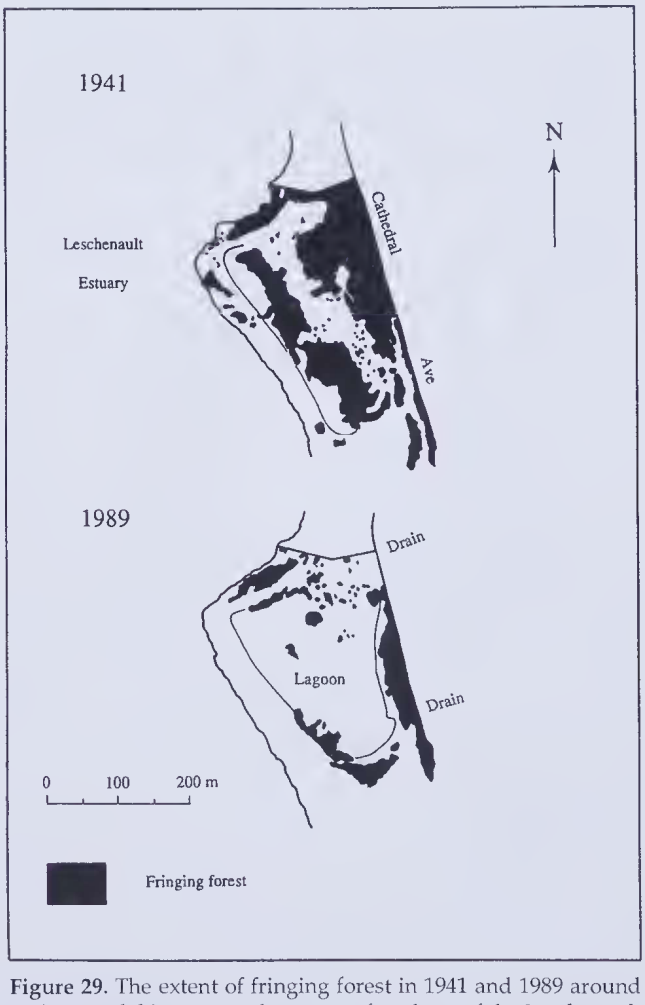


Figure 29. The extent of fringing forest in 1941 and 1989 around and on a tidal lagoon on the eastern foreshore of the Leschenault Estuary.

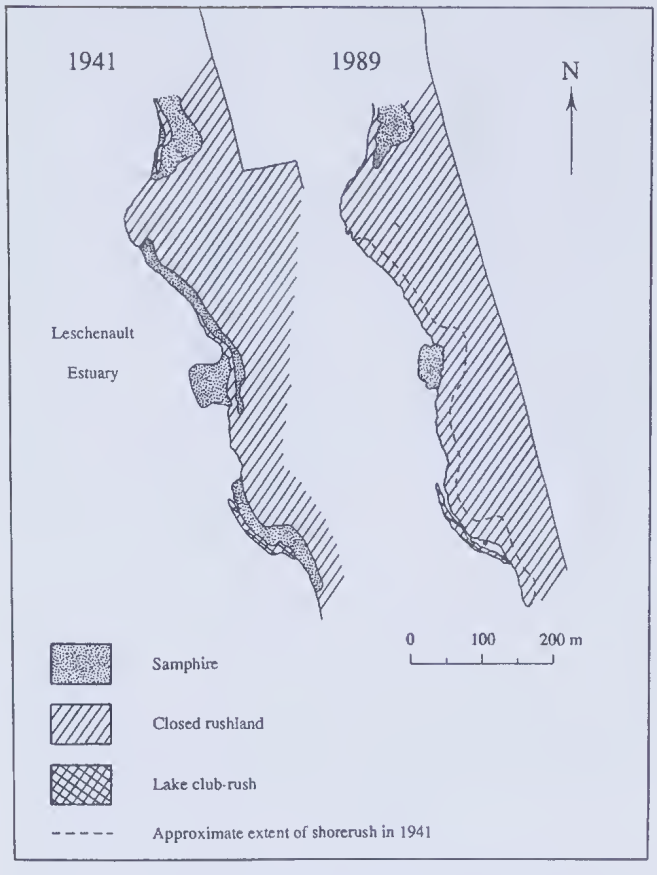


Figure 30. Extent of closed rushland and lake club-rush (*Schoenoplectus validus*) in 1941 and 1989 in a region of the north-eastern foreshore of the Leschenault Estuary.

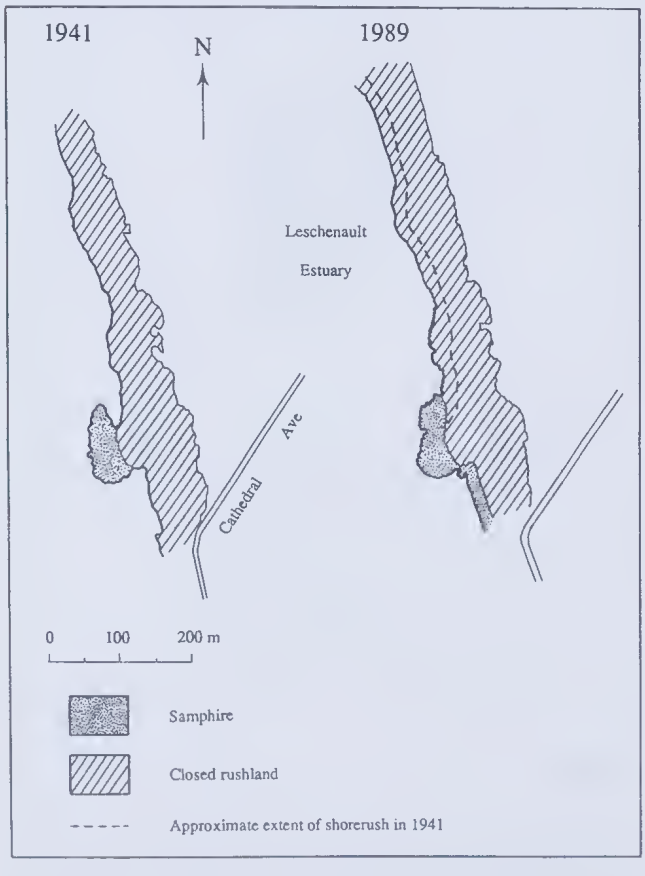


Figure 31. Extent of samphire and closed rushland in 1941 and 1989 along a region of the north-eastern foreshore of the Leschenault Estuary.

gomphocephala and/or peppermint *A. flexuosa*. The parkland areas near Australind and Point Douro today support relic flooded gum *E. rudis*, suggesting that these areas once supported stands of *E. rudis-M. rhaphiophylla* forest.

Decline of estuarine fringing forest

Prior to the development of the south-eastern corner of the estuary, the most marked decline in fringing forest was in the central area of Pelican Point (Figs 28 and 29). Fringing forests of paperbarks have been replaced by saltmarsh and the chaotic plant assemblage. This change has probably brought about by alteration to drainage patterns in the area as part of urban development. The effect has been to shift the salinity/freshwater balance in the direction of increasing salinity, favouring saltmarsh at the expense of fringing forest.

A decline in fringing forest to the north-east of the estuary (Fig 28), particularly of saltwater paperbark *M. cuticularis* and swamp paperbark *M. rhaphiophylla* had already occurred before 1941 (white tree trunks evident in aerial photographs, and confirmed by field observations of dead and dying trees). As this decline predates "The Cut" and no alteration to the drainage of the area is obvious, it is difficult to explain. If a local increase in salinity had been the cause, the nearby salt-pans, where salinity levels are at an extreme and preclude all fringing plant growth, would have increased in size, however, they have largely remained unaltered since 1941.

The death of fringing forest in the lagoon area north of Crimp Crescent is probably due to a general increase in salinity brought about by artificial drainage (Fig 29). This is also indicated by the death of *J. kraussii* (which probably once formed the understorey of the forest), and its replacement by samphire species and by a stand of Bullrush (*Typha orientalis*) in one corner of the lagoon. The replacement of *J. kraussii* by samphire indicates a recent increase in salinity while the bulrush encroachment suggests localised freshwater flushing caused by artificial drainage of the adjacent waterlogged pastures. In other words, a steady year long flushing of the lagoon area by groundwater has been replaced by more centralised drainage, causing an increase in salinity over most of the area and a decrease in salinity in specific areas, probably at certain times of the year only.

However, there is some evidence of recent fringing forest regeneration. Near Crimp Crescent a small stand of *M. viminea* low open-closed forest (Fig 17), which is associated with very saline conditions, has been slowly growing in size since at least 1941. Further, the presence of young trees of swamp paperbark (*M. rhaphiophylla*), *M. viminea* and saltwater paperbark (*M. cuticularis*) indicate a resurgence of fringing forest in some parts of Pelican Point.

Encroachment of *Juncus kraussii* closed rushland

In most areas of the estuary where the foreshore is fringed with *J. kraussii*, the species is encroaching into the estuary, and moving across samphire flats, beach sands, or the sandy estuarine substrate. Considerable encroachment into the estuary is evident at four locations (Figs 30 and 31), and aerial photographic evidence suggests an encroachment rate of 5-20 m over the last 50 years. On site,

this encroachment is evident by the growth of rhizomes with tapering leaf height, the smaller leaves being present at the growing end of the rhizome.

This estuary-ward encroachment of fringing sedges and rushes may have been caused by a reduction in mean water level over the winter months as a result of the construction of "The Cut". Several field observations support this. Firstly, *J. kraussii* occurs at two levels along the estuary shore: near estuarine waters it resides at a much lower level than to landward, indicating together with other observations, recent growth has occurred at a distinctly lower level. Secondly, there has been erosion and subsequent undermining of *J. kraussiii* along the south-western foreshore near "The Cut"; here, the 10-20 cm deep rich organic matter and root-mesh layer which supports *J. kraussii* is being undermined as waves or currents wash away the underlying sandy substrate. Locally, *J. kraussii* has established in front of the erosional cliff. In general, it would appear that a reduction in mean estuarine water level increased the exposure of an area of sandy substrate, and subsequently waves at low tide and possibly currents at high tide eroded the substrate eventually exposing and undermining the peat layer of the sedgeland. Concomitantly, reduced water level enabled *J. kraussii* to become established, probably vegetatively, at a lower level of the estuary in front of the site of erosion. In other parts of the estuary, free of erosion, *J. kraussii* simply colonised the new lower tidal sites which had become favourable for growth. If the encroachment is due to the effects of "The Cut", then it has occurred since 1951, suggesting an encroachment rate of 5-20 m over the past 40 years.

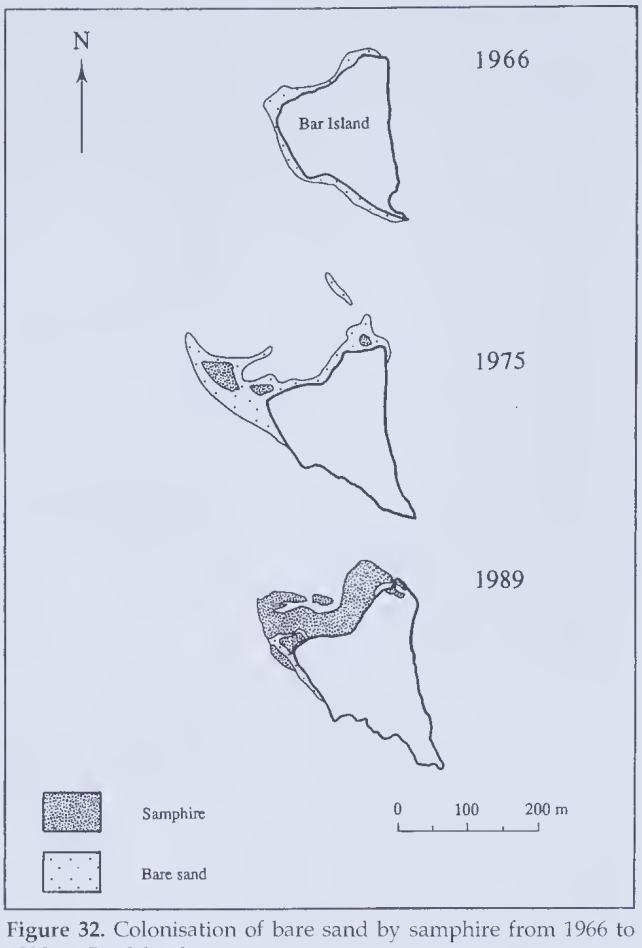


Figure 32. Colonisation of bare sand by samphire from 1966 to 1989 on Bar Island.

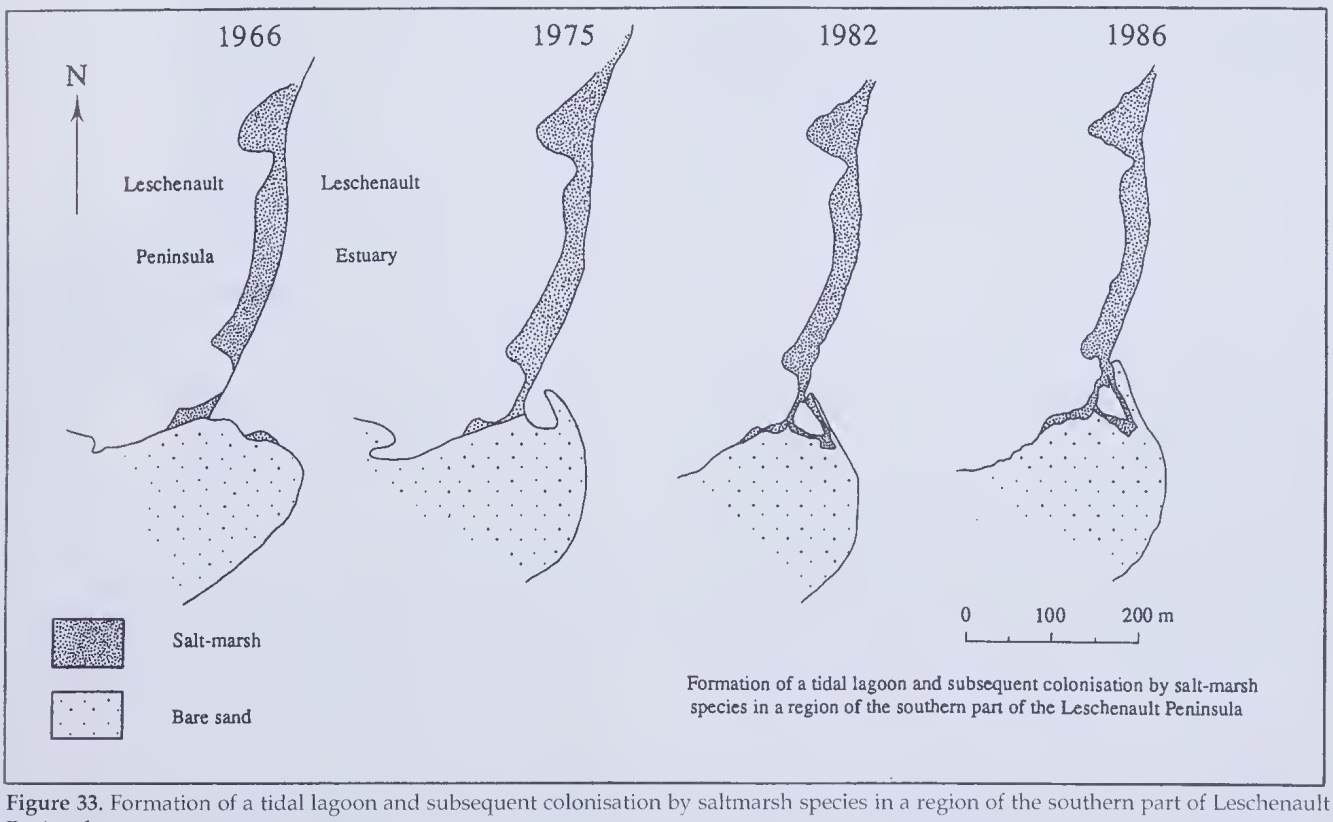


Figure 33. Formation of a tidal lagoon and subsequent colonisation by saltmarsh species in a region of the southern part of Leschenault Peninsula.

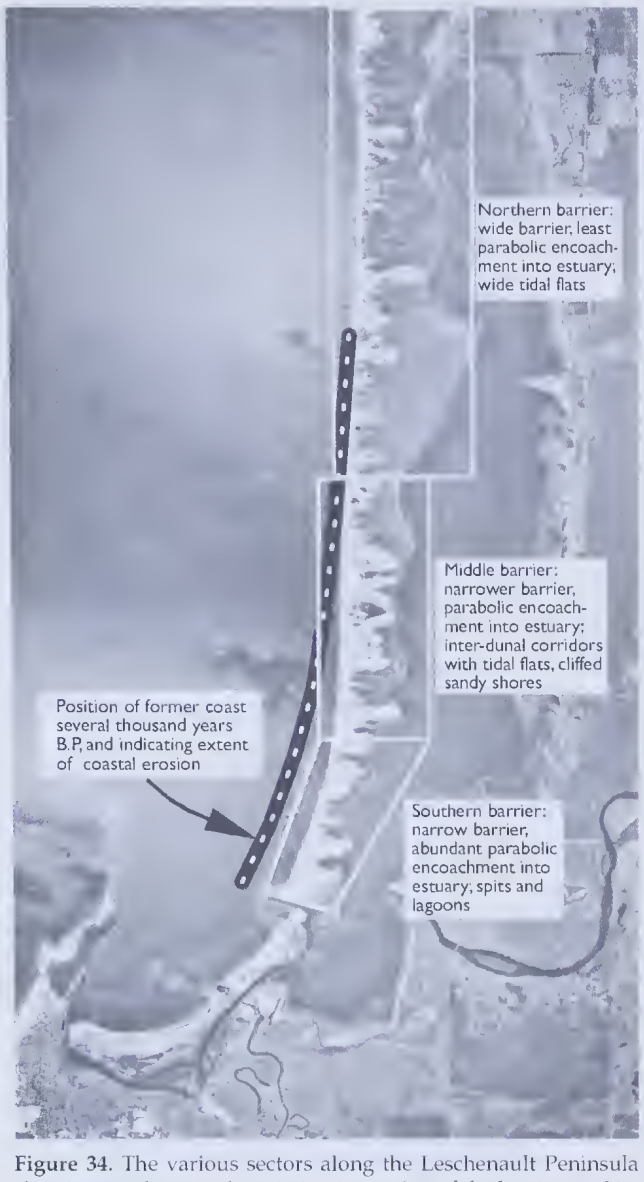


Figure 34. The various sectors along the Leschenault Peninsula showing south to north variation in erosion of the barrier, and its effect on parabolic dunes encroaching into the estuary.

Colonisation of river deltas

The colonisation of recently deposited river sediments by fringing estuarine vegetation can be rapid (Pen 1981). Colonisation by samphire of the sandy deposits at the north-western end of the mid-channel island at the mouth of the Collie River delta has largely occurred since 1975 (Fig 32). More extensive colonisation by fringing vegetation occurred on the recently formed artificial Preston River delta (now removed) and the enclosed mud-flats at Point Mornington. In these areas *Sarcocornia quinqueflora* complex and *J. kraussii* closed sedgeland completely colonised the low-lying mud flats over a ten-year period from 1977 and presently *Casuarina obesa* low open forest has developed on the high central area on the east bank.

Tidal lagoons/pools along high tidal platforms

Along the southern foreshore of the Leschenault Peninsula there are a number of small tidal lagoons or pools. These have formed by encroachment of parabolic dunes, followed by dune tip erosion by currents moving in a north to north-west direction causing the formation of a sand bar which entraps a body of water within a roughly triangular shaped area (Fig 33). Over the years, fringing vegetation colonised this area and gradually encroached upon the pool, and eventually, through the accretion of aeolian sand and organic matter, fringing vegetation colonised the entire area, forming a small triangular shaped saltmarsh. There are many examples of such areas along the southern half of the Peninsula.

As the bar-and-lagoon systems evolve from barred water bodies to gradually infilling lagoon, the vegetation assemblage changes. There is a progressive change from sand-filled lagoon barred by a sandy spit, to a sand, muddy sand and organic matter-filled lagoon to a sand and organic matter-filled emergent wetland. The vegetation that progressively inhabits these lagoons is zoned in response to salinity gradients, and in response to the amount of freshwater that seeps into the system from the adjoining dunes. The sequence of vegetation development is summarised below as bar-and-lagoon stages 1-3 in terms of the stage of development of bar-and-lagoon, the sediment fills and salinity gradients, and the types of vegetation developed. During stage 1, the bar-and-lagoon is an aquatic lagoon, barred by a spit. Its substrate is sand and muddy sand, remnant from tidal and subtidal environments of an inter-parabolic dune corridor. It is inhabited by *Ruppia*, or similar aquatic macrophyte, in subtidal environments.The saline margins are inhabited by Sarcocornia and *J. kraussii*. Sandy rise vegetation inhabits the spit or bar. During stage 2 the bar-and-lagoon is a seasonally inundated basin. Aeolian sand, and organic matter continue to fill the basin. There is saline water recharge from the estuary, and locally freshwater seepage from the dunes. The basin is inhabited by zoned vegetation: central parts of the basin are inhabited by samphire such as Sarcocornia, and Halosarcia, and upper parts of basins are inhabited by *Juncus kraussii* and *Casuarina obesa*, or where there is significant freshwater seepage by *Melaleuca rhaphiophylla*. Sandy rise vegetation inhabits the spit or bar. During stage 3, the bar-and-lagoon system is an emergent wetland basin. Aeolian sand and organic matter continue to fill the basin. There is saline water recharge from the estuary, or locally freshwater seepage from the dunes. The central basin is covered by *J. kraussi*, with *M. rhaphiophylla* over *J. kraussii* and *I. nodosus* to landward (if dominated by freshwater seepage), or by *M. cuticularis* (if there is reduced freshwater seepage), or by *C. obesa* (if estuarine water recharge dominates the hydrology). Sandy rise vegetation inhabits the spit or bar.

Weed invasions

The main weeds and alien species invading and replacing estuarine shoreline vegetation include couch *Cynodon dactylon*, kikuyu *Pennisetum clandestinum*, salt water couch *Paspalum vaginatum*, buffalo grass *Stenotaphrum secundatum*, pigface *Carpobrotus edulis*, coojong *Acacia saligna*, Bullrush *Typha orientalis*, and club rush *Bolboschoenus caldwellii*.

The most significant weed invasion along the shore of the estuary is in fringing *Juncus kraussii* formations. For

Table 2. Variation of barrier, shore types, habitat and gradients north-south along the Leschenault Peninsula, and its effect on the parabolic dune influenced estuarine shore

Location along barrier	Description of barrier, and extent of oceanic erosion	Shore types developed along estuary margin	Habitats and groundwater dynamics
northern barrier	wide barrier, least seaward face erosion, and hence fewer parabolic dunes encroaching into estuary	broad tidal flats, with mud derived from tidally deposited northward-drift transported suspended mud	mud flats, estuary source water recharge and evaporation to develop hypersaline fields; little effect of freshwater seepage from barrier dunes
middle barrier	narrower barrier, more seaward face erosion, and hence more abundant parabolic dunes encroaching into estuary	shore line dominated by parabolic dunes with broad intervening tidal flats and embayments in inter-dune corridors; mud derived from reworking of platforms, is deposited tidally in corridors, alternating with cliffed dunes where estuarine erosion is incising into the shores	mud flats between dune fingers/ridges; estuary-source water recharge and evaporation to develop hypersaline fields; effects of freshwater seepage from barrier dunes along interfaces between dunes and tidal flats
southern barrier	narrowest part of barrier, in the zone of the most extreme seaward face erosion, and hence most abundant parabolic dunes encroaching into estuary	shore line dominated by active parabolic dunes, and cliffed parabolic dunes, with spits, bars and lagoons; small intervening lagoons, tidal flats and embayments in inter-dune corridors; mud is deposited tidally in corridors	embayments and mud flats between dune fingers/ridges, barred by spits derived from dune tips; the zone of the most complex groundwater hydrodynamics, with dunes, spits/bars, and mudflats exerting influence on groundwater from estuary-sources, rainfall, and dune groundwater seepage. Because of abundance and proximity of parabolic dunes, and direct control of dunes on coastal landforms, this area exhibits maximum effects of freshwater seepage on coastal vegetation

instance, along the south-eastern foreshore, grasses and other weeds are invading from the adjacent parkland into the landward side of the narrow shoreline closed sedgeland of *J. kraussii*. The common weeds are couch, kikuyu, water couch, buffalo grass and pigface. The shoreward edge of the sedgeland remains relatively free of weeds, although water couch often forms mats on areas of exposed sand. A reduction in mean water level brought about by "The Cut" together with the clearing of native vegetation behind the *J. kraussii* strip and its subsequent replacement by grasses and other weeds provide explanations for this invasion. A reduction in mean water level would not only mean that *J. kraussii* could encroach upon the estuary but that the vegetation assemblages, probably dominated by twig-rush *B. juncea*, knotted club-rush *I. nodosa* and swamp paperbark *M. rhaphiophylla* could have encroached upon the *J. kraussii* assemblage. However, these landward assemblages, having been replaced by grasses and other weeds, have not been present to respond to the change in environmental conditions. Instead the weeds have responded and are slowly invading and replacing the *J. kraussii* zone.

The small tree and native weed coojong is colonising successfully along the north-eastern foreshore of Leschenault Inlet, where it is favoured by frequent fires (Pen 1992). It is a common member of freshwater fringing forest assemblages and has formed dense stands in some areas.

Bullrush and native club rush locally are colonising the estuary shore, but while elsewhere these species are abundant along the Swan-Canning River Estuary, either fringing the rivers or invading the saltmarshes receiving additional channelled stormwater input, their effect in Leschenault Inlet is as yet minor. Bullrush is present in some localities receiving freshwater via drains or freshwater seepage at the base of dunes. Club-rush is found in a few localities fringing tidal pools and along the Preston River. The distribution of these two species is limited to localised reductions in salinity, and thus neither presently represents a major threat to native plant assemblages.

Paspalum vaginatum forms extensive grassy mats on beach sand and narrow mats in and about *J. kraussii* on the immediate foreshore in some areas. Along the Preston River it forms dense partially floating mats and may be found in association with club-rush *Bolboschoenus*. Although alien, it helps to stabilise the foreshore and does not appear to prevent the colonisation or regeneration of native species. However, landward of the foreshore it can be an invasive

species contributing to the replacement of *J. kraussii* on higher and dryer ground. It can also form dense mats in areas of saltmarsh receiving freshwater input, but its status as an invader in these circumstances is uncertain and requires further investigation.

The climber bridal creeper *Asparagus asparagoides* is abundant in the low open closed forest assemblage of *Melaleuca rhaphiophylla* and *Agonis flexuosa* north of Crimp Crescent. Elsewhere, outside of Leschenault Inlet (*e.g.* the Canning River), this species is a troublesome weed and has the capacity to smother native shrubs and juvenile trees, and so must be regarded as a potential threat to this assemblage.

Shoreline vegetation, geomorphic setting and salinity

There appear to be four determinants controlling the extent and type of saltmarsh present along the shore. The two most important two influences are geomorphic setting and physical estuarine coastal processes. The third is a south to north gradient in source water salinity, and the fourth is anthropogenic effects.

At the largest scale, the Leschenault Inlet estuary has several shore settings as habitats for peripheral vegetation; geomorphic context and groundwater settings are the main formative processes. The habitat settings are: 1) the eastern shore of the estuary, developed as a laterally consistent sand platform and shore, cut into the Mandurah-Eaton Ridge, provides a relatively consistent shore habitat in terms of coastal landforms, substrates, and estuary-derived and hinterland-derived groundwater hydrodynamics; 2) the digitate delta of the Collie River, with an array of heterogeneous habitats, reflecting heterogeneity of intra-deltaic landforms, substrates, and groundwater systems; 3) the tidally-influenced delta of the Preston River, with an array of heterogeneous habitats, also reflecting heterogeneity of intra-deltaic landforms, substrates, and groundwater systems; and 4) the western to northern shore of the estuary, with a south to north heterogeneous array of coast types, reflecting large scale variation in abundance of parabolic dunes reaching the shore of the estuary. This variation results in a south to north variability in coastal landforms, coastal processes, substrates, and effects of tidal zone groundwater hydrodynamics and dune-derived fresh water seepage, as described below.

The barrier of the Leschenault Peninsula is rapidly eroding (Semeniuk & Searle 1987), with an erosion rate of up to 1 m annually. In the longer term, over the latter part of the Holocene, there has been a variation in the rate over the length of the Peninsula, with the most marked erosion occurring in southern parts, and less erosion in northern parts of the barrier. As a result, the barrier is narrower to the south. The dynamics of this south to north variation, and its effect on parabolic dunes encroaching on the estuary, is summarised in Table 2. and in Fig 34.

The third determinant, estuarine source water for the tidal flats has a subtle effect on vegetation type in a south to north gradient along the shore of the estuary. The main part of the tidal zones is recharged by estuarine water. Thereafter, once emplaced, the near-surface groundwater and soilwater are subject to evaporation, or dilution by meteoric recharge. In this context, given that there is a similar evaporative field across the tidal flats from north to south induced by solar radiation and by wind, and a similar influx of meteoric water, any variation of groundwater and soilwater salinity may be expected to be primarily determined by the salinity of the source water. As noted earlier, Wurm & Semeniuk (2000) describe four fields in the salinity of the aquatic portion of the estuary: 1) a marine to hypersaline northern portion; 2) a large marine central portion; 3) a marine to brackish southern portion; and 4) a deltaic portion. These various source water salinities have the potential to influence the salinity of upper tidal groundwater and soilwater.

The best location to unravel the effects of estuarine source water salinity variation is the eastern estuary shore. Here, at the large scale, there is not the south to north habitat variation, and hence the shore could be viewed as exhibiting a consistency of habitat within which south to north groundwater variability may be expressed by vegetation composition and structural variation. However, anthropogenic effects are more prevalent and impact on the shore vegetation. Nonetheless, in our estimation, recognising from site to site the effects of anthropogenic activities on coastal vegetation in terms of salinity changes and vegetation changes (as described above in an earlier section of this paper), there appears to be a south to north variation in composition of saltmarsh vegetation reflecting the source water salinity variation. These patterns of saltmarsh type in relation to regional salinity fields are summarised as follows: 1) in the southern part of the estuary, where estuarine waters are marine to brackish, the shore vegetation is dominated by *J. kraussii*; 2) in the middle part of the estuary, where estuarine waters are mainly marine water, the shore vegetation is dominated by *J. kraussii*; and 3) in the upper part of the estuary, where estuarine wasters are marine to hypersaline, the shore vegetation is dominated by *S. quinqueflora*.

The fourth determinant is anthropogenic, relating to the effects of altered drainage, and groundwater hydrodynamics brought about by draining, clearing, dewatering, urbanisation, dredging and spoil disposal, and road construction. These effects variably and locally have changed the recharge dynamics, discharge dynamics, and salinity of coastal habitats, resulting in the changes in assemblage composition, and mortality of some species.

It is difficult to disentangle the effects of habitat variation and source water salinity to explain the distribution of saltmarsh vegetation in a south to north gradient along the western Leschenault Inlet estuarine shore, from a perspective of natural dynamics alone, since anthropogenic effects here are at a minimum. What may be viewed as an increase in salt-tolerant species from south to north, perhaps reflecting the south to north variation in salinity of estuarine source water, may also be viewed as a reflection of the greater development and availability of mud-floored tidal flats, and the diminishing effect of freshwater seepage from neighbouring dunes. The complexity of the inter-relationship of gradients in coastal landforms, their internal groundwater dynamics, and effects of a variable estuarine source water salinity, however, must await further study.

Comparison with other estuaries:

The Leschenault Inlet estuary and its peripheral habitats and vegetation are briefly compared with five other estuaries and peripheral vegetation along the south-western and southern coast in terms of landform setting, heterogeneity of coastal landforms and peripheral vegetation habitats (Table 3), peripheral vegetation species composition, and diversity of vegetation assemblages (Table 4). The estuaries and coastal systems considered in this comparison are: Swan-Canning Estuary; Peel-Harvey estuary; Walpole-Nornalup estuary; Princess Royal Harbour; and Oyster Harbour. These results suggest the following ranking of estuaries in terms of the richness of their peripheral vegetation associations (the number grading is derived from Table 4 with 20 the highest, and 10 the least significant): Leschenault Inlet estuary (20); Walpole-Nornalup Inlet (20); Swan River estuary (17); Princess Royal Harbour (16); Oyster Harbour (16); and Peel-Harvey estuary (10).

Discussion

The Leschenault Inlet estuary presents a heterogeneous array of shore habitats, resulting from a variable upland geomorphic setting (*i.e.* the south to north gradient along the west coast, and east-coast *vs* west-coast *vs* north-coast setting), the variable coastal processes operating on the coast (to generate progradational mud flats *vs* cliffed dune shores *vs* bar-and-lagoon complexes *vs* tidal platforms), upland to estuarine groundwater hydrodynamics and interactions, deltaic build-up at river mouths, and a complex sealevel history to develop stranded estuarine landforms. In contrast, its subtidal habitats are relatively simple and extensive. In a State-wide perspective, the array of peripheral and aquatic habitats are exclusive to Leschenault Inlet, with this system being the only estuarine lagoon in Western Australia situated leeward of a retreating dune barrier. As such, the complex array of estuarine coastal landforms and peripheral vegetation habitats are regionally significant, notwithstanding that some of the vegetation assemblages are regionally widely distributed.

Table 3. Comparison between geomorphic setting and peripheral estuarine habitats of the main south-western and southern estuaries

Estuary	landform setting and processes	heterogeneity of coastal landforms and peripheral vegetation habitats
Swan-Canning Estuary	inundated valley tract of the Swan and Canning Rivers, traversing a range of coastal plain geomorphic units	the shores are mainly erosional forms cut into limestone or sand, with local depositional nodes such as beachridges on meanders; thus, small scale habitats are sandy beaches, small barred lagoons, limestone cliffs, mud and muddy sand platforms
Peel-Harvey estuary	located at junction between limestone ridge and Bassendean Dune terrain	range of complex shore types dependent on location within the estuary (Semeniuk & Semeniuk 1990): modern and stranded tidal deltas, stranded sand flats, limestone cliff shores, spits and lagoons, beaches, fluvial deltas
Leschenault Inlet estuary	located behind high Holocene dune barrier, and encroaching on high sandy Mandurah-Eaton Ridge	range of complex shore types dependent on location within the estuary (this paper), related to east-coast *vs* west coast *vs* north coast settings, and in relationship to encroaching dunes: high tidal platforms, bar-and-lagoon complexes, beaches, cliffed dune shores, deltas
Walpole-Nornalup Inlet estuary	located in inundated hilly terrain of Precambrian rock, and barred by a Holocene dune barrier	peripheral habitats related to edge of stable dune barrier, deltas, and the steep slopes cut into Precambrian bedrock; habitats include: narrow tidal flats, beaches, delta landforms, rocky shores
Princess Royal Harbour	located in inundated hilly terrain of Precambrian rock, barred by barrier dune, and tombolo	peripheral habitats related to edge of granitic/saprolitic hills, edges of sand dune barrier and tomboloes, and fluvial lowlands; habitats include sandy beaches, tidal flats, small barred lagoons
Oyster Harbour	located in inundated hilly terrain of Precambrian rock and undulating sand plain	peripheral habitats related to edge of granitic/saprolitic hills, reworked edge of an undulating sand plain, and deltaic landforms; habitats include sandy beaches, tidal flats, small barred lagoons, deltaic systems

Table 4. Dominant native fringing plant species of selected south-western and southern estuaries

Species	Swan (Pen 1983)	Peel-Harvey (Backshall & Bridgewater 1981, Semeniuk & Semeniuk 1990.)	Leschenault (Pen 1992, 1993)	Walpole-Nornalup Inlet (unpublished data)	Princess Royal Harbour (Pen 1992)	Oyster Harbour (unpublished data)
Samphire marsh						
Sarcocornia quinqueflora	***	***	***		***	***
Wilsonia humilis			*		**	*
Hemichroa pentandra					***	*
Suaeda australis	***	**	***		**	**
Samolus repens	**		**		***	*
Triglochin striata	*		*		*	
Bolboschoenus caldwellii	**		*			
Halosarcia halocnemoides	***	***	***			*
Halosarcia indica bidens	***	**	***			
Halosarcia lepidosperma						***
Frankenia pauciflora	*(?)	*	***			
Gahnia trifida	(?)	*	*		*	*
Fringing vegetation or freshwater sedgeland						
Juncus kraussii	***	***	***	***	***	***
Baumea juncea	*		*		***	
Baumea spp sedgeland				*		
Isolepis nodosa			*		***	
Maireana oppositifolia						**
Atriplex hypoleuca					***	**
Calocephalus brownii					*	
Lepidosperma gladiatum					*	
Leptocarpus tenax				*		
Lepidosperma effusum				*		
Leucopogon obovatum				*		
Mangrove						
Avicennia marina			*			
Estuarine fringing forest / scrub						
Casuarina obesa	**	**	**			
Melaleuca cuticularis	*(?)	**	***	***	***	***
Melalenca viminea	*(?)		*	*		
Melaleuca microphylla				*		
Freshwater fringing forest						
Eucalyptus rudis	***		***			
Melaleuca rhaphiopylla	***	**	***	***		
Melaleuca preissiana	*			*		*
Agonis flexuosa			*	*	***	*** *Agonis*
parviceps				*		
Callistachys lanceolata				***		** *Euca-*
lyptus cornuta						*
Astartea fascicularis				**		
Banksia littoralis				*		
Eucalyptus patens				*		
Hakea linearis				**		
Homalospermum firmum				***		
Kunzea sulphurea				**		
Total score	17	10	20	20	16	16

Asterisks (***, **, *) indicate relative importance to the characterisation of the fringing plant assemblages;
(?) indicates difficult to assess due to clearing of vegetation and lack of clarity on old aerial photos.

The species assemblages along the shore of the Leschenault Inlet estuary are not more diverse than in other estuaries in south-western Australia. The species in this area are relatively common in other estuaries, and most of the assemblages find expression elsewhere albeit in reduced or restricted settings. What is important in Leschenault Inlet is the complex array of estuarine coastal habitats, and the salinity gradients developed therein have resulted in the development of a range of vegetation units that are distributed in mosaics and gradients across the various habitat types of the shoreline. Thus, the variation in assemblages across the three stages of development of bar-and-lagoon systems, or across the low bar and associated shallow shore-parallel lagoons on the high-tidal platforms represent distinct and important landscape ecological associations. This feature is important given that the stages of habitat development are dynamic *i.e.* they are on-going, and represent active habitat-evolving ecologic systems.

The complexities of the inter-relationship of vegetation to local and regional gradients in coastal landforms, the internal groundwater dynamics, and the effect of a south to north variation in estuarine source water salinity have not been fully explored in this study. However, the shore of the Leschenault Inlet estuary has the potential to provide a valuable natural laboratory for integrated vegetation-ecological investigations unlike any other estuary in south-western Australia. In this context, Leschenault Inlet estuary represents a classic classroom for student studies and research in estuarine peripheral vegetation ecology.

Additionally, Leschenault Inlet represents a valuable geoheritage and biodiversity resource. This is from a perspective of conservation given the array of vegetation units across the range of peripheral habitats, and the coastal landforms relating to a south to north gradient in landforms, coastal processes, groundwater hydrodynamics, and the effects of a variable and complex sealevel history (unique amongst the south-western and southern estuaries to Leschenault Inlet).

As noted above, in comparison to the other estuaries in Western Australia, the shoreline habitats and vegetation comprising the periphery of the Leschenault Inlet estuary rank as the most significant along the south-western coast of the Swan Coastal Plain, and ranks with the Walpole-Nornalup Inlet system which itself is located in the richest botanical district in south-western Australia. The presence of associations with winter ephemeral herbs and grasses within the peripheral vegetation formations links the Leschenault Inlet estuary with associations otherwise common only in Victoria (Bridgewater 1982) and indicates the special nature of Leschenault Inlet along the Western Australian coast.

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